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(12) United States Patent
Hine et al.

(10) **Patent No.: US 9,051,037 B2**

(45) **Date of Patent: *Jun. 9, 2015**

(54) **WAVE POWER**

(71) Applicant: **Liquid Robotics, Inc.**, Sunnyvale, CA (US)

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(73) Assignee: **Liquid Robotics, Inc.**, Sunnyvale, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 38 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **13/753,377**

(22) Filed: **Jan. 29, 2013**

(65) **Prior Publication Data**

US 2014/0038477 A1 Feb. 6, 2014

Related U.S. Application Data

(63) Continuation of application No. 13/199,646, filed on Sep. 6, 2011, now Pat. No. 8,376,790, which is a continuation of application No. 12/087,961, filed as application No. PCT/US2007/001139 on Jan. 18,

(Continued)

(51) **Int. Cl.**

B63H 1/36 (2006.01)
B63H 19/02 (2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ***B63H 1/36*** (2013.01); *B63B 2035/006* (2013.01); ***B63H 19/02*** (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC B63H 1/36; B63H 19/02; B63H 25/04; B63H 2025/028; B63H 2025/045; B63B 2035/0006; Y02E 10/38; Y02T 70/59

USPC 114/293; 440/3, 9, 13, 17, 18, 19, 20

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

986,627	A	3/1911	Fischer
1,067,113	A	7/1913	Heyen

(Continued)

FOREIGN PATENT DOCUMENTS

BE	570555	A	9/1958
CN	1280936	A	1/2001

(Continued)

OTHER PUBLICATIONS

Ageev. M., "Application of solar and wave energies for long-range autonomous underwater vehicles", Advanced Robotics, 2002, p. 43-55, vol. 16, No. 1.

(Continued)

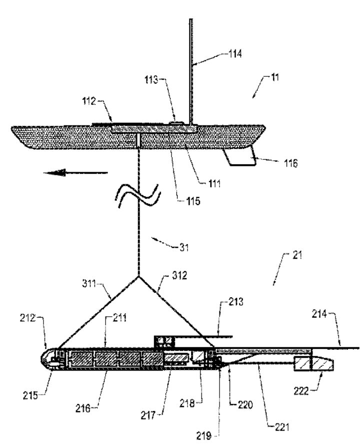
Primary Examiner — Lars A Olson

(74) *Attorney, Agent, or Firm* — Kilpatrick Townsend & Stockton LLP

(57) **ABSTRACT**

A wave-powered water vehicle includes a surface float, a submerged swimmer, and a tether which connects the float and the swimmer, so that the swimmer moves up and down as a result of wave motion. The swimmer includes one or more fins which interact with the water as the swimmer moves up and down, and generate forces which propel the vehicle forward. The vehicle, which need not be manned, can carry communication and control equipment so that it can follow a course directed by signals sent to it, and so that it can record or transmit data from sensors on the vehicle.

12 Claims, 16 Drawing Sheets



Related U.S. Application Data

2007, now Pat. No. 8,043,133, which is a continuation-in-part of application No. 11/436,447, filed on May 18, 2006, now Pat. No. 7,371,136.

(60) Provisional application No. 60/760,893, filed on Jan. 20, 2006, provisional application No. 60/841,834, filed on Sep. 1, 2006.

(51) **Int. Cl.**

B63B 35/00	(2006.01)
B63H 25/04	(2006.01)
B63H 25/02	(2006.01)

(52) **U.S. Cl.**

CPC *B63H 25/04* (2013.01); *B63H 2025/028* (2013.01); *B63H 2025/045* (2013.01); *Y02E 10/38* (2013.01); *Y02T 70/59* (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

1,315,267	A	9/1919	White
2,170,914	A	8/1939	Rummler
2,520,804	A	8/1950	Hollar
2,668,512	A	2/1954	Klas
2,868,504	A	1/1959	Minty
3,132,322	A	5/1964	Maes
3,297,814	A	1/1967	McClean et al.
3,312,186	A	4/1967	Litshiem
3,341,871	A	9/1967	Oliveau
3,352,274	A	11/1967	Clakins
3,443,020	A	5/1969	Loshigian
3,453,981	A	7/1969	Gause
3,508,516	A	4/1970	Root
3,613,627	A	10/1971	Kennedy
3,760,441	A	9/1973	Handelman
3,828,380	A	8/1974	Lebovits et al.
3,845,733	A	11/1974	Jackman
3,859,949	A	1/1975	Toussaint et al.
3,860,900	A	1/1975	Scudder
3,872,819	A	3/1975	Pickens
3,889,045	A	6/1975	Logsdon
3,928,967	A	12/1975	Salter
3,962,982	A	6/1976	Marchay et al.
3,978,813	A	9/1976	Pickens et al.
4,134,023	A	1/1979	Salter
4,224,707	A	9/1980	Mariani
4,332,571	A	6/1982	Jakobsen
4,371,347	A	2/1983	Jakobsen
4,383,725	A	5/1983	Bogese et al.
4,389,843	A	6/1983	Lamberti
4,462,211	A	7/1984	Linderfelt
4,598,547	A	7/1986	Danihel
4,610,212	A	9/1986	Petrovich
4,638,588	A	1/1987	Abadie
4,673,363	A	6/1987	Hudson et al.
4,684,350	A	8/1987	DeLima
4,684,359	A	8/1987	Herrington
4,726,314	A	2/1988	Ayers
4,763,126	A	8/1988	Jawetz
4,842,560	A	6/1989	Lee
4,896,620	A	1/1990	Jones
4,968,273	A	11/1990	Momot
4,981,453	A	1/1991	Krishan et al.
5,050,519	A	9/1991	Senften
5,084,630	A	1/1992	Azimi
5,577,942	A	11/1996	Juselis
5,675,116	A	10/1997	Hillenbrand
5,678,504	A	10/1997	Toplosky et al.
5,690,014	A	11/1997	Larkin
5,902,163	A	5/1999	Barruzzi et al.
6,099,368	A	8/2000	Gorshkov
6,194,815	B1	2/2001	Carroll
6,260,501	B1	7/2001	Agnew
6,285,807	B1	9/2001	Walt et al.
6,408,792	B1	6/2002	Markels, Jr.
6,561,856	B1	5/2003	Gorshkov
6,665,189	B1	12/2003	Lebo
6,756,695	B2	6/2004	Hibbs et al.
6,814,633	B1	11/2004	Huang
6,908,229	B2	6/2005	Landrieve et al.
6,980,228	B1	12/2005	Harper
7,350,475	B2	4/2008	Borgwarth et al.
7,371,136	B2	5/2008	Hine et al.
D578,463	S	10/2008	Treaud et al.
7,472,866	B2	1/2009	Heaston et al.
7,641,524	B2	1/2010	Hine et al.
7,955,148	B2	6/2011	Corradini
8,043,133	B2	10/2011	Hine et al.
8,205,570	B1	6/2012	Tureaud et al.
8,808,041	B2	8/2014	Hine et al.
8,944,866	B2	2/2015	Hine et al.
2002/0178990	A1	12/2002	McBride et al.
2003/0009286	A1	1/2003	Shibusawa et al.
2003/0174206	A1	9/2003	Moroz
2003/0220027	A1	11/2003	Gorshkov
2004/0102107	A1	5/2004	Gorshkov
2004/0217597	A1	11/2004	Carroll et al.
2006/0213167	A1	9/2006	Koselka
2007/0051292	A1	3/2007	Kilbourn et al.
2007/0173141	A1	7/2007	Hine et al.
2008/0188150	A1	8/2008	Hine et al.
2008/0294309	A1	11/2008	Kaprielian
2008/0299843	A1	12/2008	Hine et al.
2009/0107388	A1	4/2009	Crowell et al.
2009/0193715	A1	8/2009	Wilcox
2009/0218984	A1	9/2009	Parakulam
2009/0308299	A1	12/2009	Luccioni et al.
2009/0311925	A1	12/2009	Hine et al.
2010/0268390	A1	10/2010	Anderson
2011/0059638	A1	3/2011	Sandwith
2011/0192338	A1	8/2011	Goudeau
2012/0029696	A1	2/2012	Ota
2012/0029718	A1	2/2012	Davis
2012/0069702	A1	3/2012	Muyzert et al.
2012/0094556	A1	4/2012	Hine et al.
2012/0295499	A1	11/2012	Hine
2013/0068153	A1	3/2013	Hine
2013/0102207	A1	4/2013	Hine et al.
2014/0263851	A1	9/2014	Hine et al.
2014/0283726	A1	9/2014	Ong et al.
2014/0284998	A1	9/2014	Brennan et al.
2014/0290233	A1	10/2014	Hine et al.
2014/0335747	A1	11/2014	Hine et al.

FOREIGN PATENT DOCUMENTS

CN	268-9229	A	3/2005
CN	1715136	A	1/2006
DE	10141805	A1	5/2002
DE	10300599	A1	7/2004
DE	102007053037	A1	5/2009
DE	202008013757	U1	3/2010
EP	1369013	A1	12/2003
FR	1159028	A	6/1958
FR	2669886	A1	6/1992
GB	2461792	A	1/2010
JP	S 55-051697		4/1970
JP	S 55-152698		11/1980
JP	S 61-057488		3/1986
JP	S 63-149289		6/1988
JP	S 64-050199		3/1989
TW	221588		3/1994
TW	547434		8/2003
WO	87/04401	A1	7/1987
WO	94/10029	A1	5/1994
WO	98/39205	A1	9/1998
WO	98/46065	A1	10/1998
WO	01/42992	A1	6/2001

(56) **References Cited**

FOREIGN PATENT DOCUMENTS

WO	2007/087197 A2	8/2007
WO	2008/109002 A2	9/2008
WO	2013/077931 A2	5/2013

OTHER PUBLICATIONS

Advanced Technology Office, "Persistent Ocean Surveillance Station-Keeping", DARPA; EXIF metadata shows image created Oct. 5, 2005, 1 page.
Anderson, B. and Padovani, B., "Towards a Comprehensive Regional Acoustic Study for Marine Mammal Distribution and Activity Regulation", A Liquid Robotics White Paper, Jan. 2012.
Clement et al., Wave energy in Europe: Current status and perspectives, Renewable and Sustainable Energy Reviews, 2002, p. 431, vol. 6, No. 5.
Communication from Japanese Patent Office on Oct. 18, 2011 on Japanese Application No. 2008-551327. [English translation].
Communication from Chinese Patent Office on Aug. 24, 2011 on Chinese Application No. CN200880006903.
Darpa, "Persistent Ocean Surveillance, Station Keeping Buoys, Program Overview", Aug. 31, 2004, 19 pages.
Department of the Navy., "ONR/MTS Buoy Workshop 2006, Persistent Unmanned Autonomous Buoy", 21 pages, believed to have been published Mar. 13, 2006.
Extended European Search Report and Opinion for EP Application No. 08726305, mailed on Jan. 15, 2013, 7 pages.
International Search Report for PCT/US2008/002743, mailed Sep. 8, 2008, 3 pages.
International Search Report and Written Opinion for PCT/US2012/029696, mailed Apr. 4, 2013, 21 pages.
International Search Report and Written Opinion for PCT/US2012/029718, mailed Dec. 21, 2012, 20 pages.
International Search Report and Written Opinion for PCT/US2012/029703, mailed Oct. 17, 2012, 14 pages.
International Search Report and Written Opinion for PCT/US2012/044729, mailed Oct. 17, 2012, 11 pages.
Joanne Masters, "Liquid Robotics Ocean Robots Embark on World Record Journey Across Pacific Ocean to Foster New Scientific Discoveries", Liquid Robotics, press release Nov. 17, 2011, 2 pages, San Francisco, CA.
Jones and Young., "Engineering a large sustainable world fishery," Environmental Conservation, 1997, p. 99-104, vol. 24.
Latt, Khine. "Persistent Ocean Surveillance—Station Keeping Buoys, Program Overview", DARPA, Aug. 31, 2004, 19 pages.
Lenton and Vaughan., "The radiative forcing potential of different climate geoengineering options", Atmos. Cem. Phys. Discuss., 2009, p. 2559-2608, vol. 9.
Martin, J.H and Fitzwater, S.E., "Iron Deficiency Limits Phytoplankton Growth in the north-east Pacific Subarctic", Nature, 1988, vol. 331, p. 341-343.
Martin., "Glacial-Integral CO2 Change: The Iron Hypothesis", Paleoceanography, 1990, p. 1-13, vol. 5, No. 1.
Olson, Robert A., "Communications Architecture of the Liquid Robotics Wave Glider".
Phelps, Austin. "Wave-Powered Motor Propels Model Boat", Popular Mechanics, Aug. 1949, pp. 182-183.
Rainville, Luc. "Wirewalker: an Autonomous Wave-Powered Vertical Profiler", Aug. 19, 2001, 7 pages.
Shaw, Albert. "The American Monthly Review of Reviews—An International Magazine", vol. 19, Jan.-Jun. 1899, 2 pages.
Solomon, S. et al., "Irreversible climate change due to carbon dioxide emissions", Proc. Natl. Acad. Sci. USA, 2009, vol. 106, No. 6, p. 1704-1709.
Sparks, David. "Persistent UnManned Autonomous Buoy (PUMA)", ONR/MTS Buoy Workshop 2006, SeaLandAire Technologies, Inc., Mar. 15, 2006, Texas A&M University, College Station, 26 pages.
Wilcox, S. et al. "An autonomous mobile platform for underway surface carbon measurements in open-ocean and coastal waters", In Proceedings MTS/IEEE Oceans 2009, Biloxi, MS, Oct. 2009.
Liquid Robotics (brochure), 2011, 48 pages, retrieved from [http://liquid.com/resources/press-hik.html] on Apr. 30, 2013.
Olson, Robert A., "Communications Architecture of the Liquid Robotics Wave Glider", presented at Navigation Guidance and Control of Underwater Vehicles Conference, University of Porto, Porto, Portugal, Apr. 2012, 5 pages.
International Search Report and Written Opinion of International Application No. PCT/US2012/055797, mailed May 28, 2013, 11 pages.
Non-Final Office Action for U.S. Appl. No. 13/424,156, mailed Apr. 5, 2013, 10 pages.
Non-Final Office Action for U.S. Appl. No. 13/424,239, mailed Apr. 25, 2013, 19 pages.
International Preliminary Report on Patentability for PCT Application No. PCT/US2012/029703 mailed Sep. 26, 2013, 9 pages.
International Preliminary Report on Patentability for PCT Application No. PCT/US2012/029696 mailed Sep. 26, 2013, 13 pages.
International Preliminary Report on Patentability for PCT Application No. PCT/US2012/029718 mailed Sep. 26, 2013, 13 pages.
Final Office Action for U.S. Appl. No. 13/424,156, mailed Dec. 16, 2013, 9 pages.
Notice of Allowance for U.S. Appl. No. 13/424,239, mailed Feb. 10, 2014, 11 pages.
International Preliminary Report on Patentability for PCT Application No. PCT/US2012/055797 mailed Mar. 27, 2014, 6 pages.
Notice of Allowance for U.S. Appl. No. 13/424,156, mailed Mar. 31, 2014, 18 pages.
International Preliminary Report on Patentability for International PCT Application No. PCT/US2012/044729, mailed Jan. 16, 2014, 7 pages.
Notice of Allowance for U.S. Appl. No. 13/536,935, mailed May 30, 2014, 7 pages.
International Search Report and Written Opinion for PCT Application No. PCT/US2014/020853 mailed Jul. 1, 2014, 11 pages.
Office Action for Australian Patent Application No. 2012275286 mailed Aug. 22, 2014, 6 pages.
Notice of Allowance for U.S. Appl. No. 13/621,803, mailed Sep. 23, 2014, 5 pages.
Office Action for Australian Patent Application No. 2012327253 mailed Sep. 23, 2014, 5 pages.
Office Action for Australian Patent Application No. 2012228956 mailed Sep. 25, 2014, 3 pages.
Non-Final Office Action for U.S. Appl. No. 13/424,170, mailed Oct. 2, 2014, 29 pages.
International Search Report and Written Opinion for PCT Application No. PCT/US2014/030396 mailed Oct. 14, 2014, 17 pages.
Office Action for Australian Patent Application No. 2012228951 mailed Nov. 17, 2014, 4 pages.
Office Action for Australian Patent Application No. 2012228948 mailed Nov. 27, 2014, 3 pages.
Final Office Action for U.S. Appl. No. 13/424,170, mailed Mar. 20, 2015, 13 pages.
Office Action for European Patent Application No. 12740770.8, mailed Mar. 23, 2015, 8 pages.

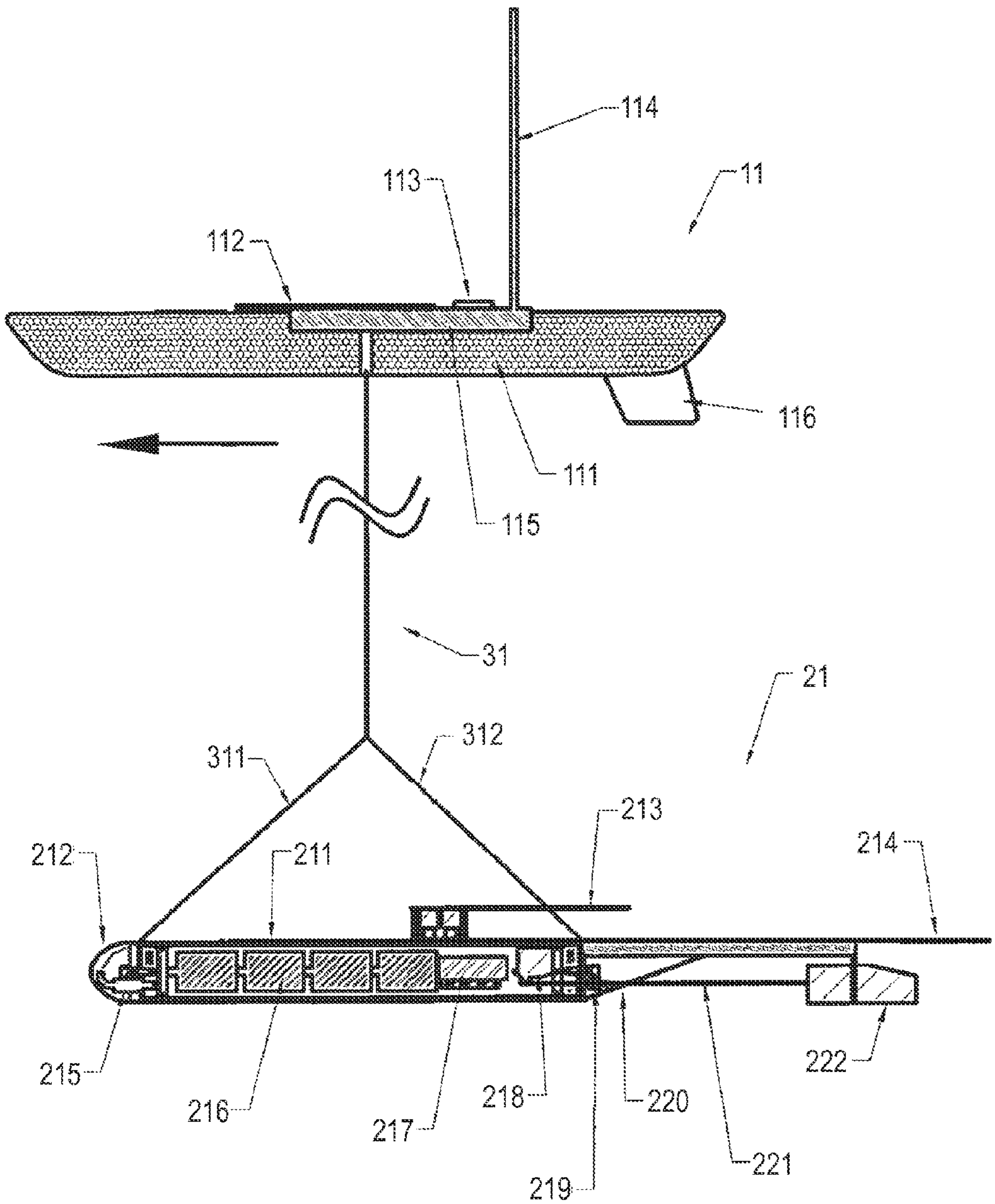

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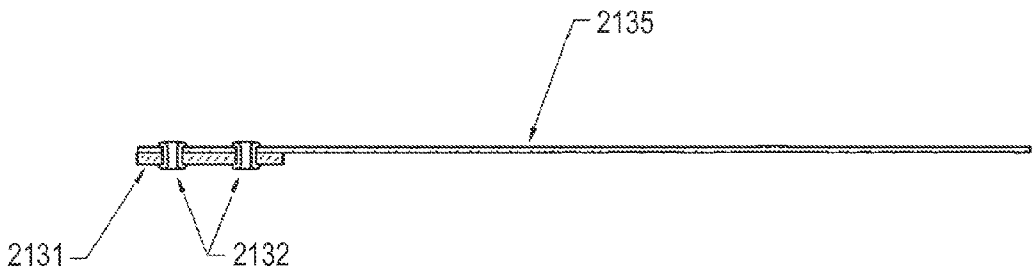
FIG. 1



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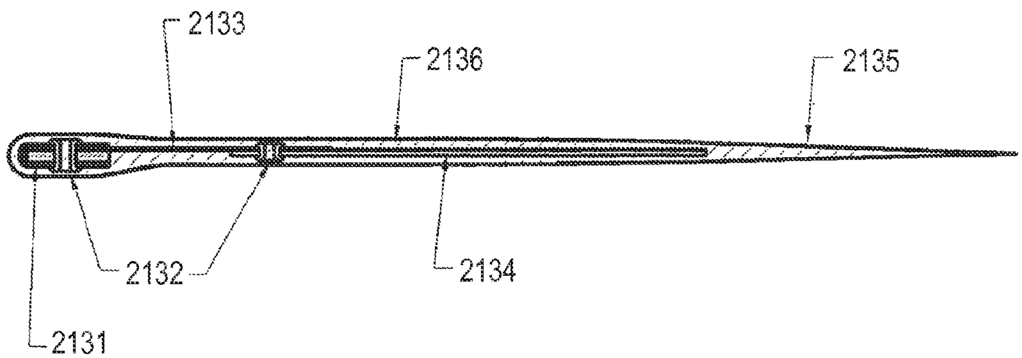

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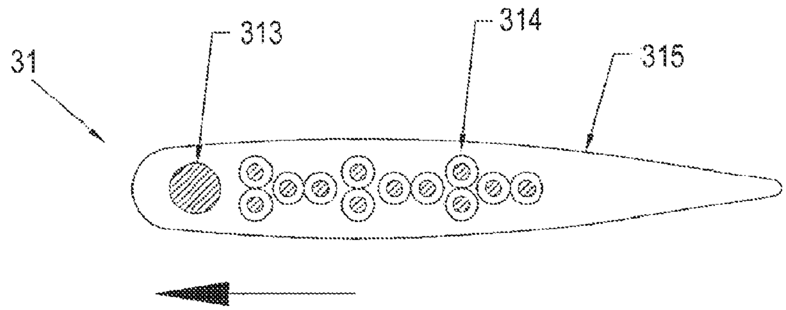

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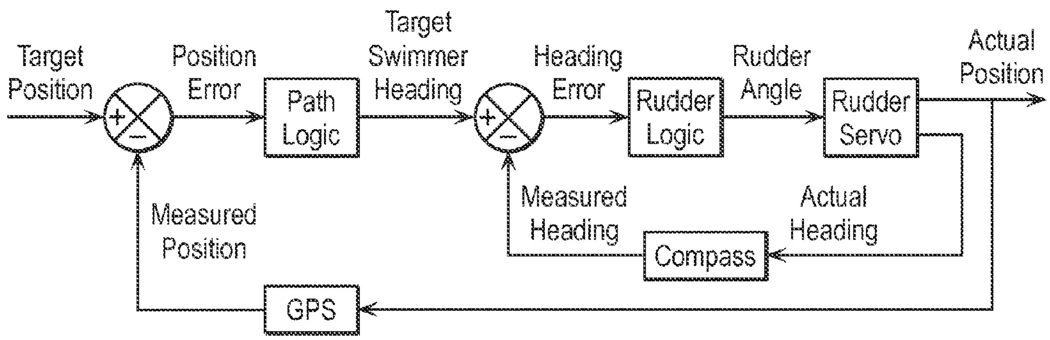
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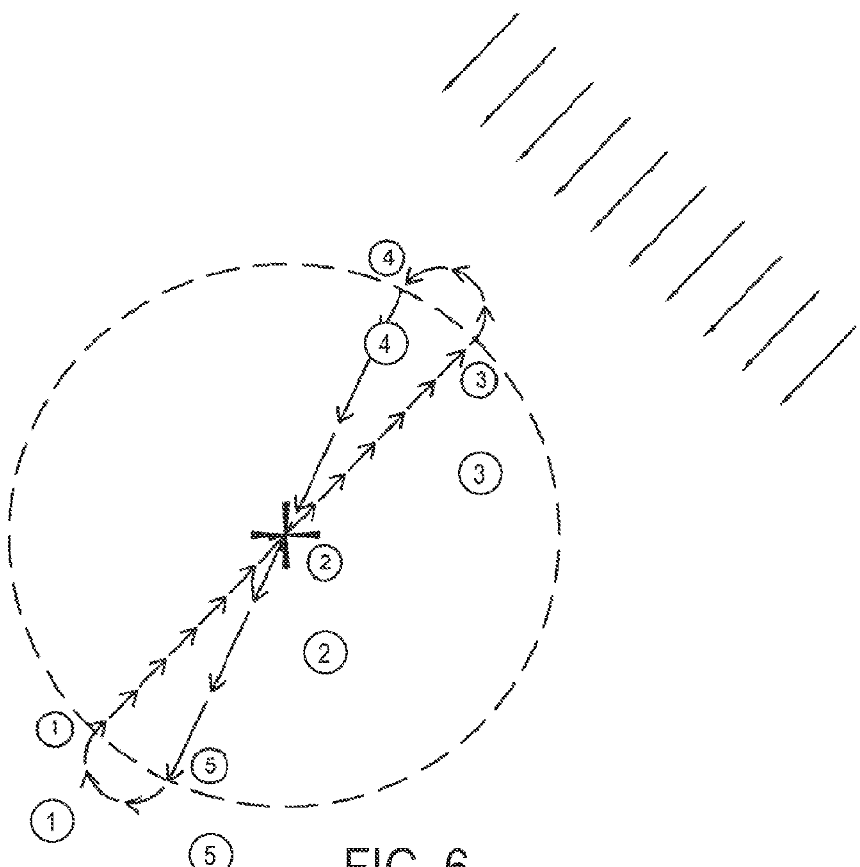
FIG. 5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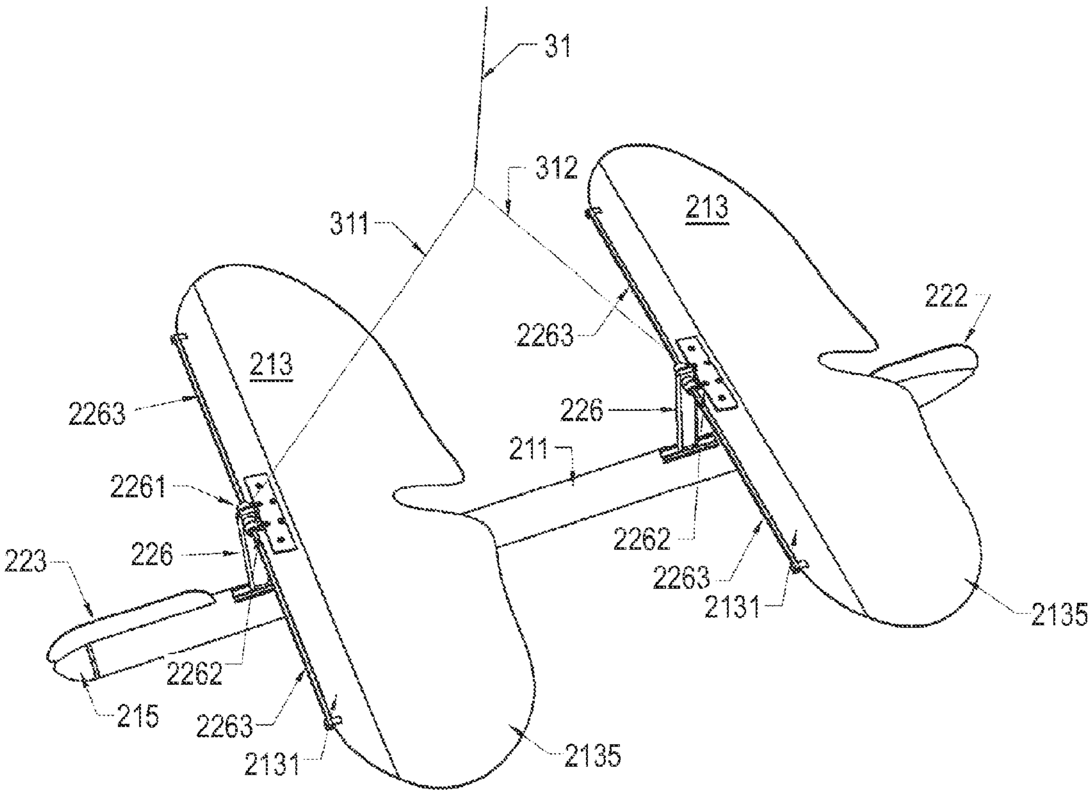
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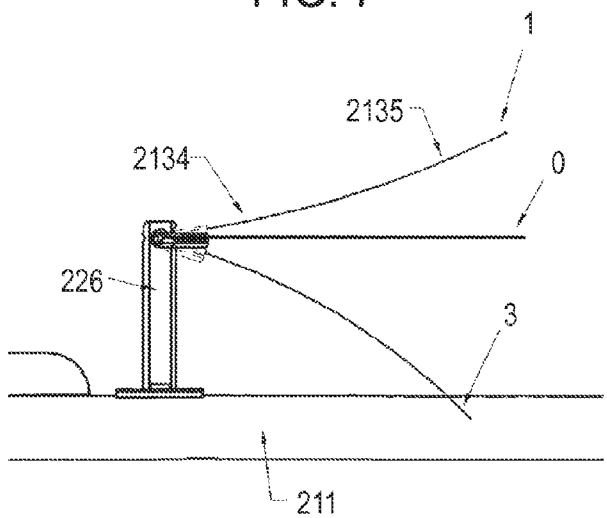
FIG. 7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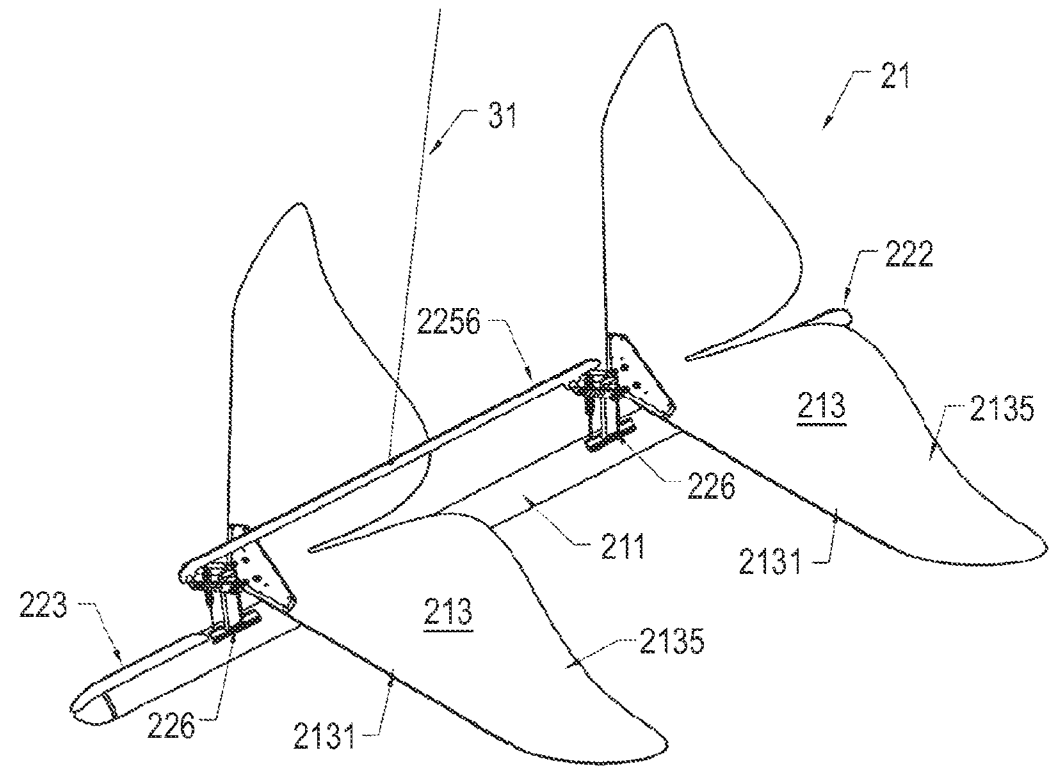
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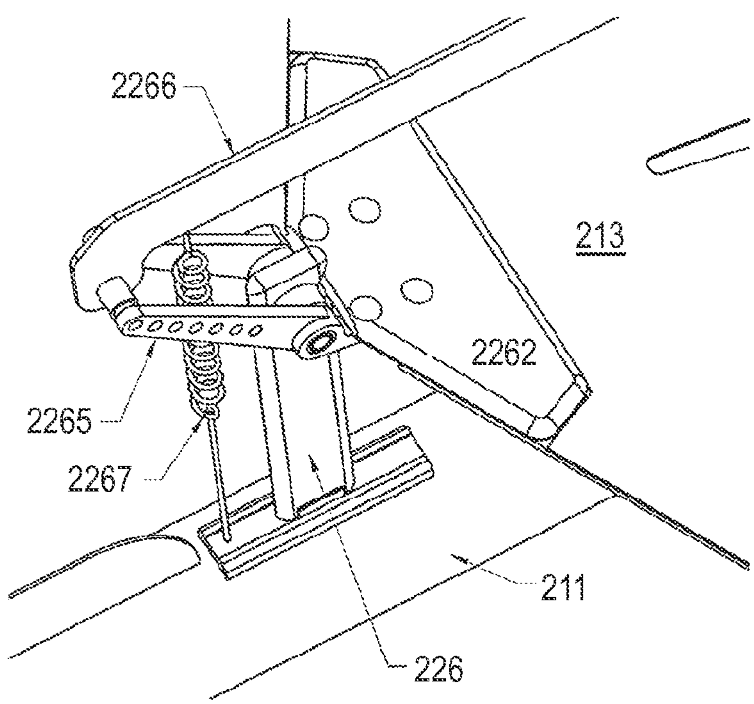
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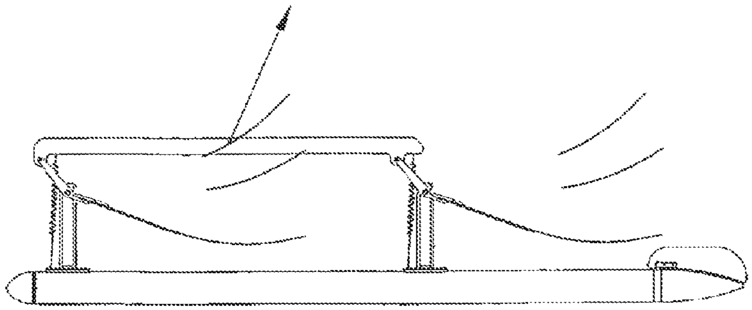
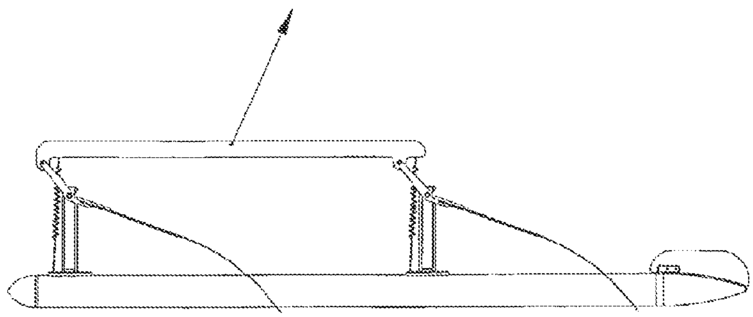


FIG. 11A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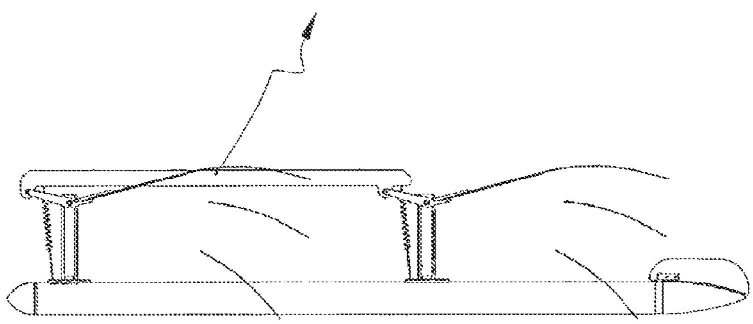
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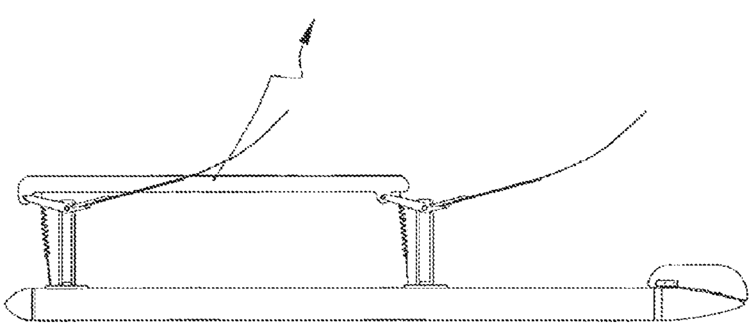
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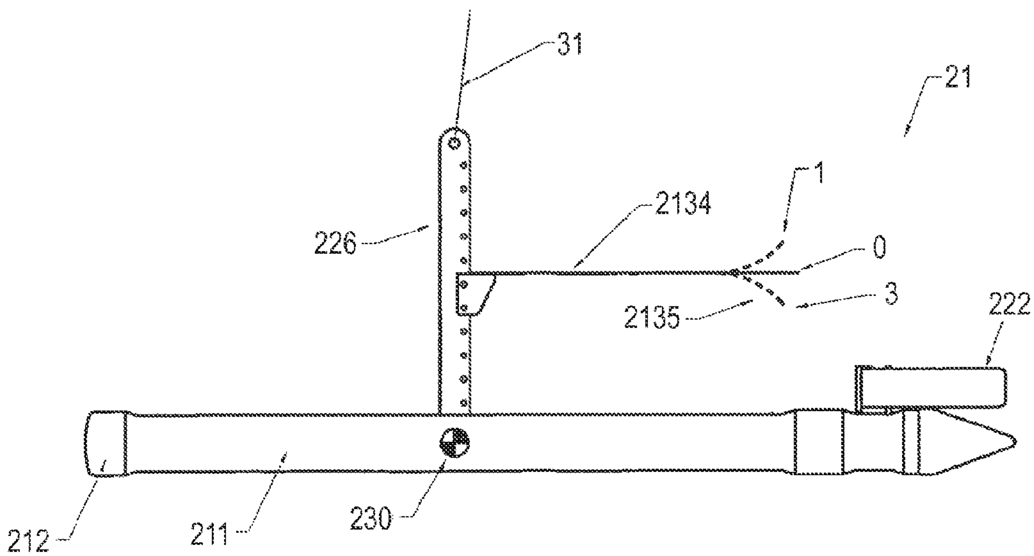
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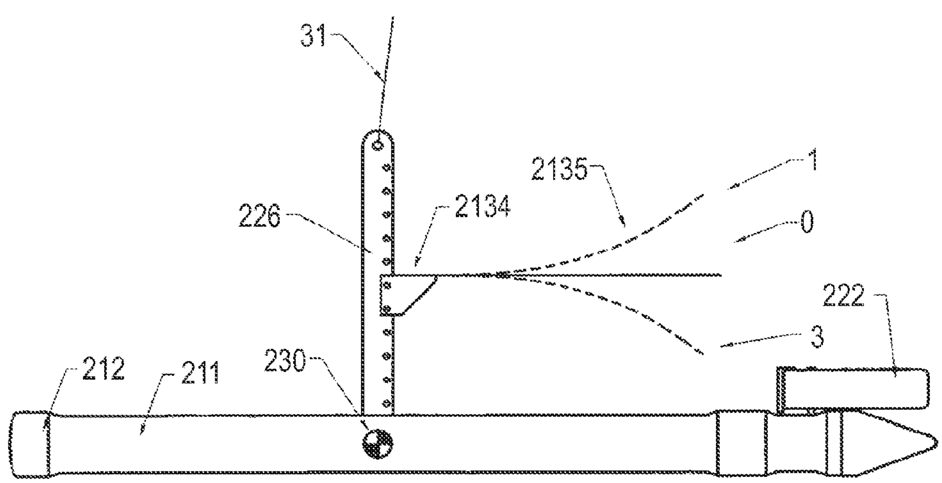
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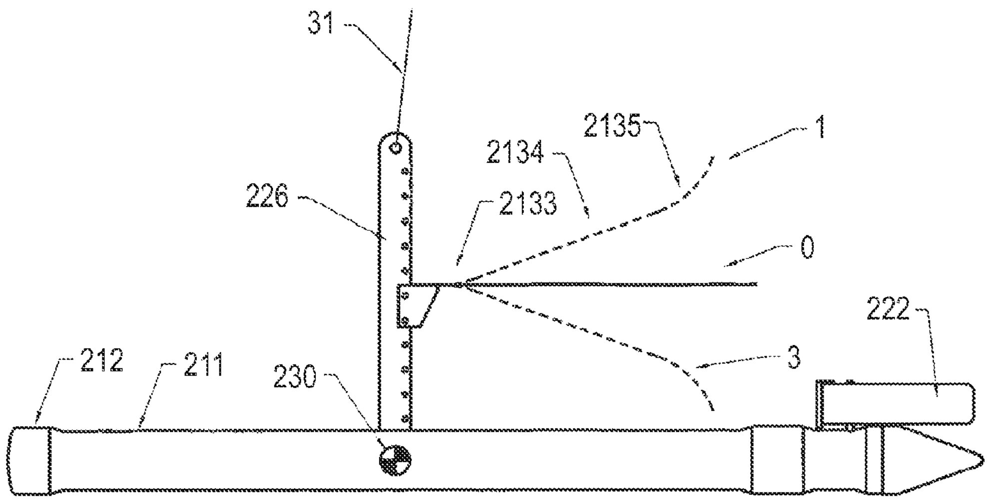
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FIG. 14

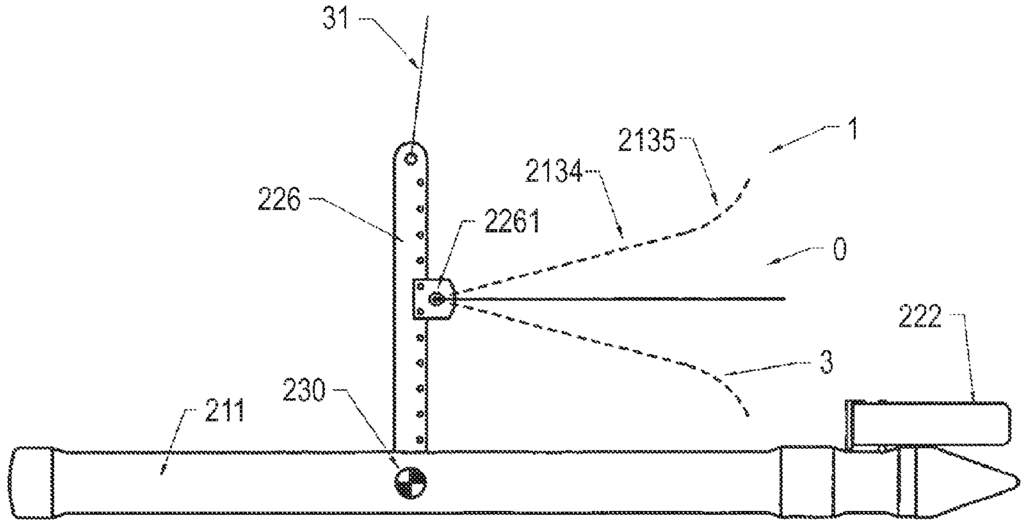
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FIG. 15

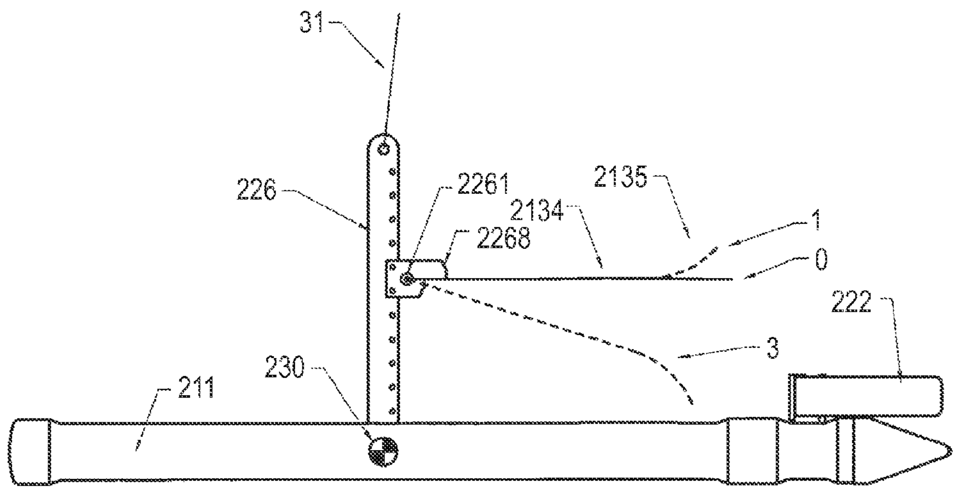
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FIG. 16

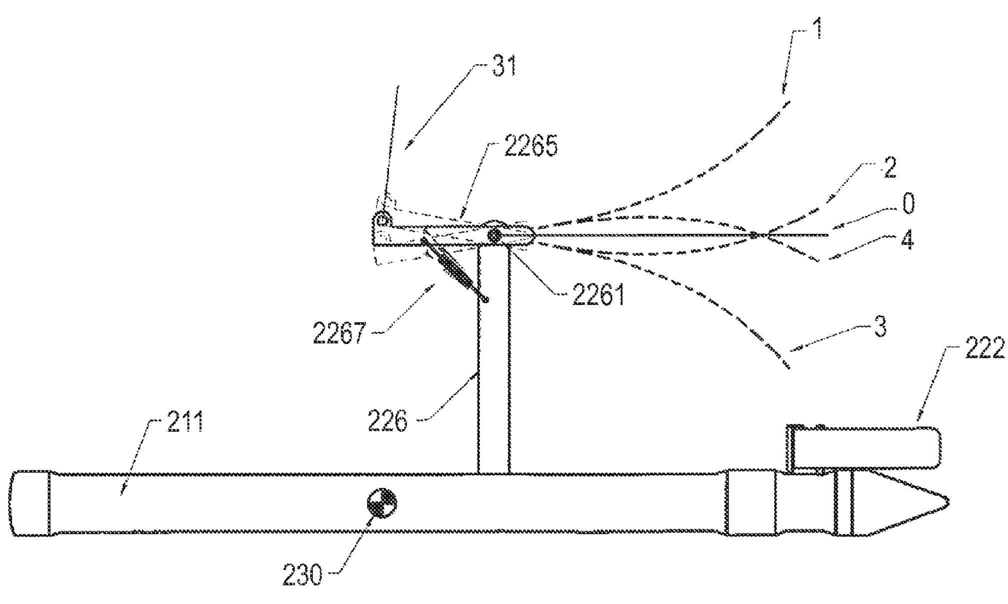
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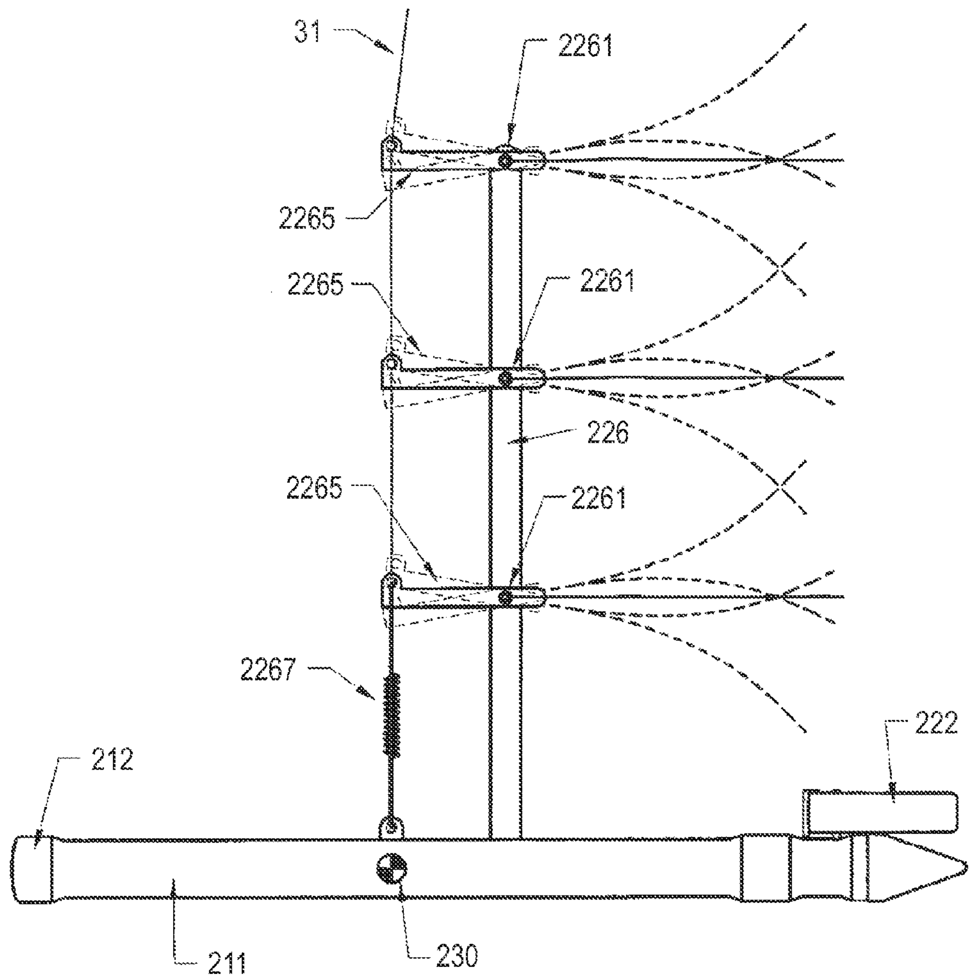
FIG. 17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2261
2265
2265
2261
226
2265
2261
2267
222
212
211
230

FIG. 18

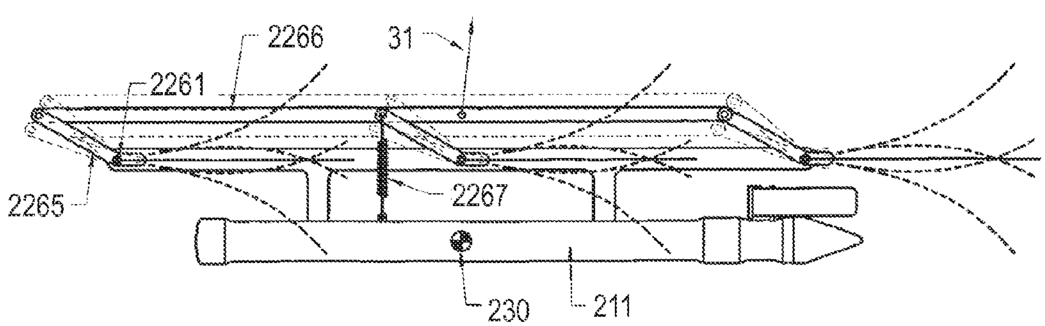
2266
31
2261
2265
2267
230
211

FIG. 19

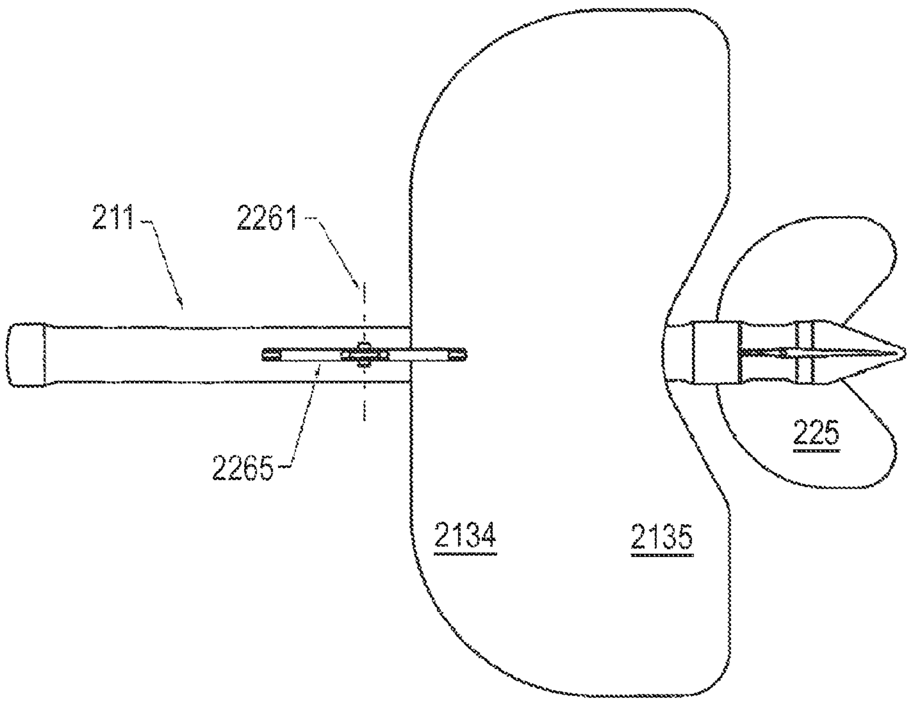
211
2261
2265
2134
2135
225

FIG. 20

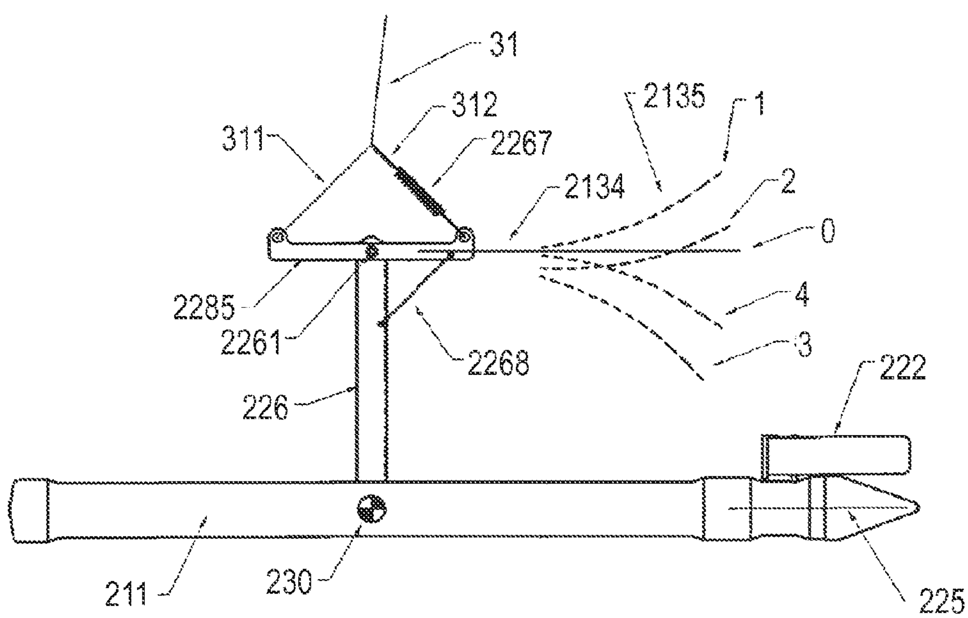
31
312
2135
1
311
2267
2134
2
0
2285
4
2261
3
2268
222
226
211
230
225

FIG. 21

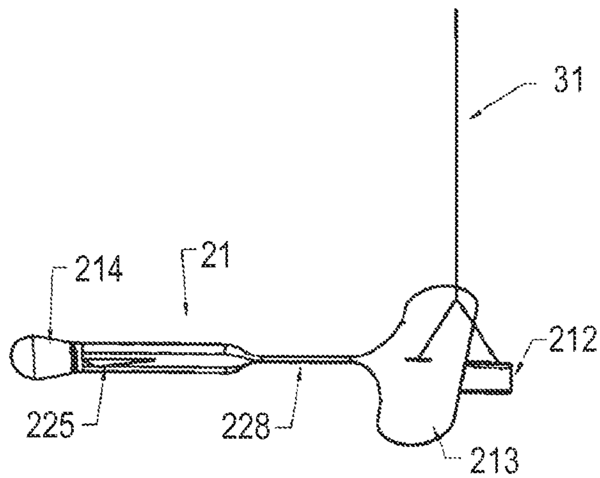

FIG. 22A

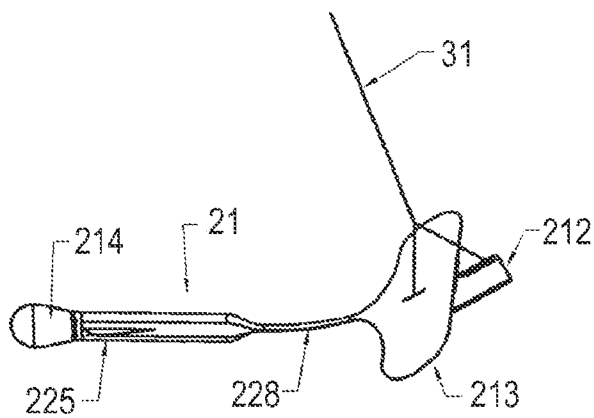

FIG. 22B

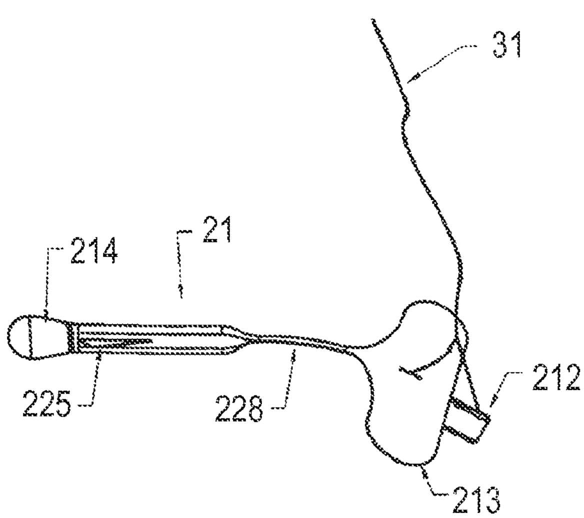

FIG. 22C

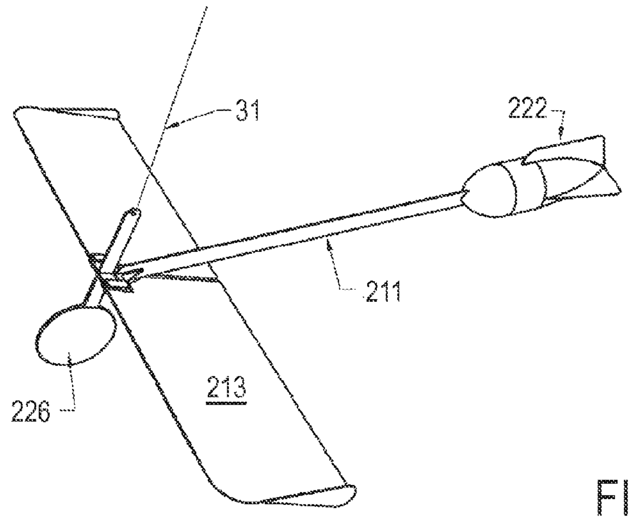

FIG. 23

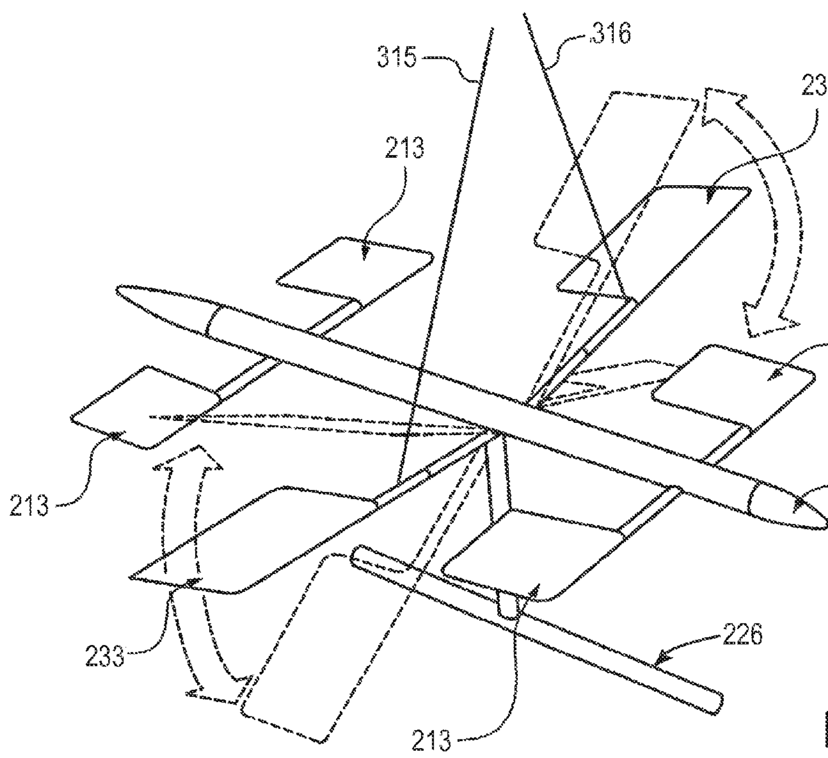

FIG. 24

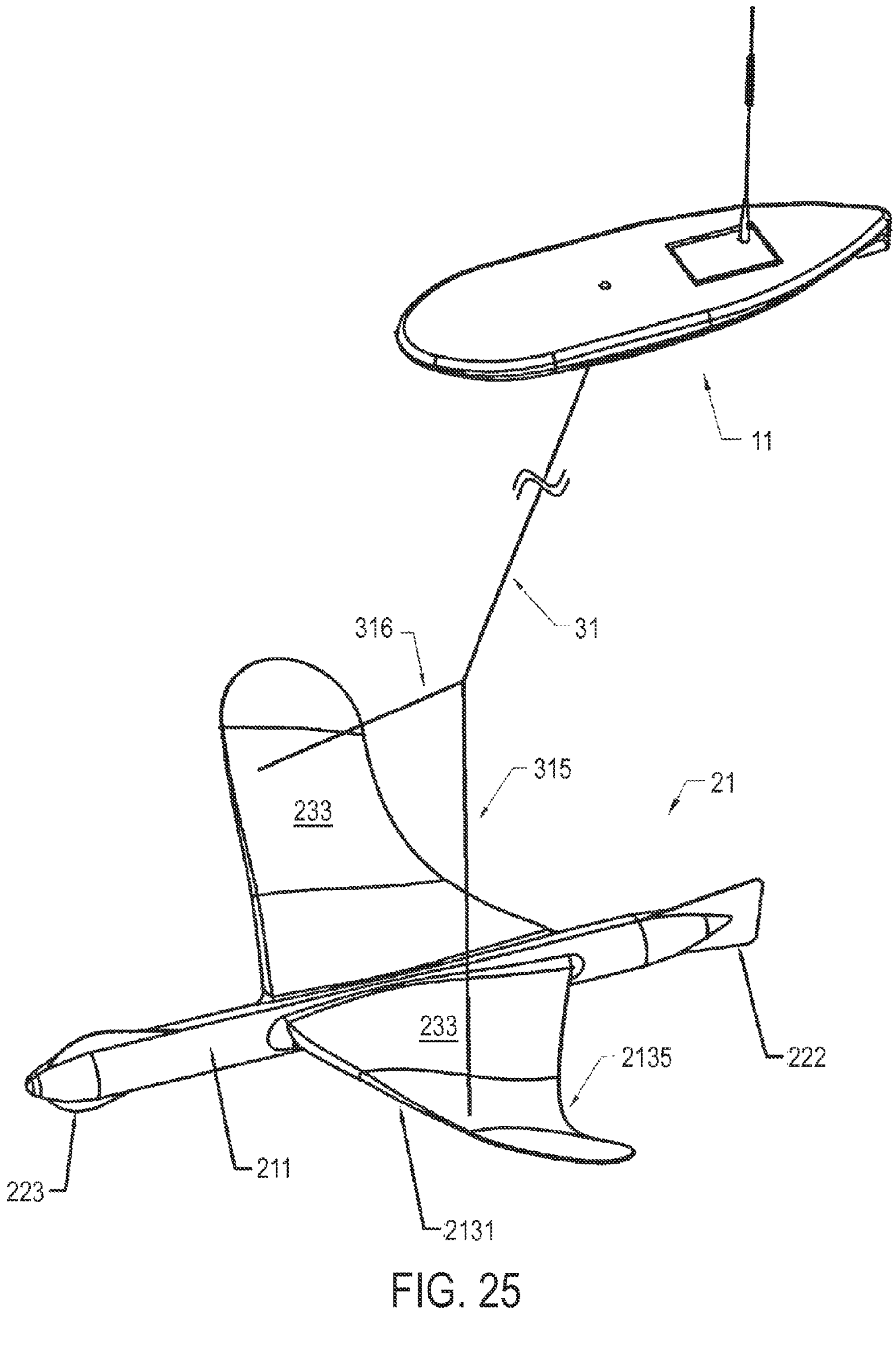

FIG. 25

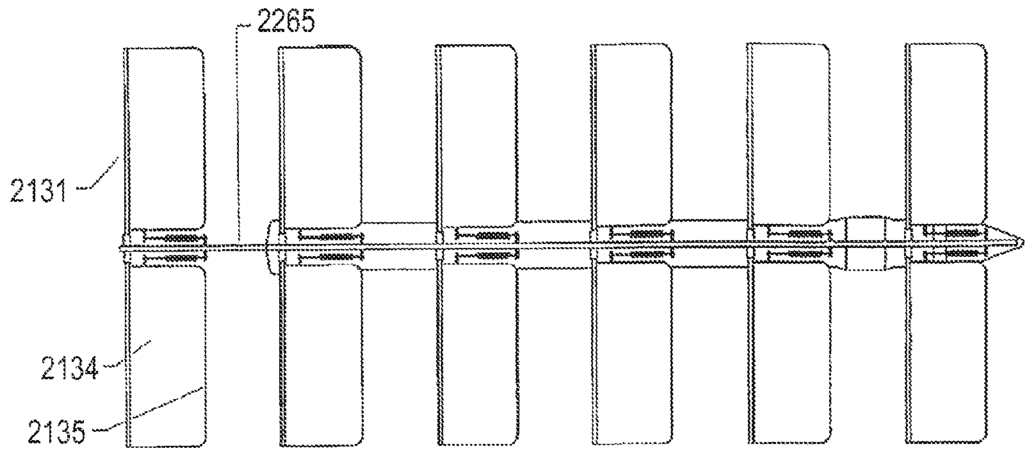

FIG. 26A

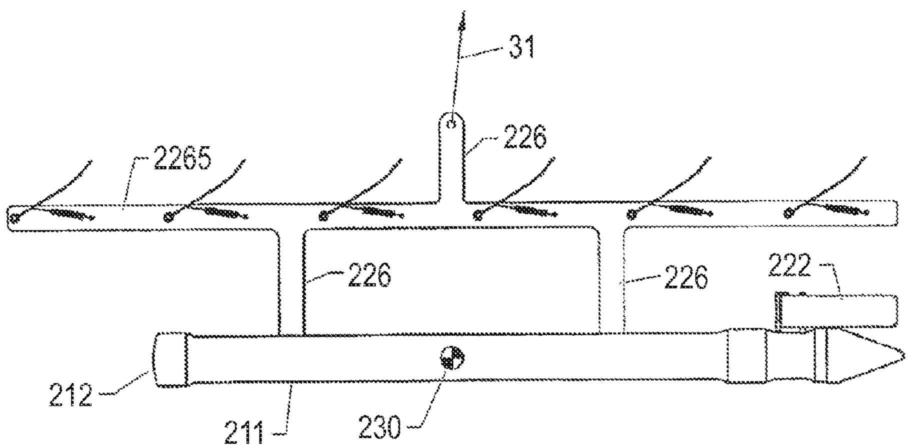

FIG. 26B

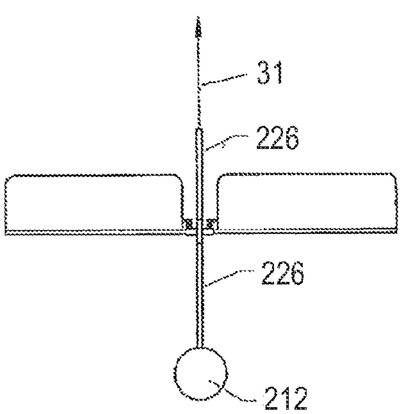

FIG. 26C

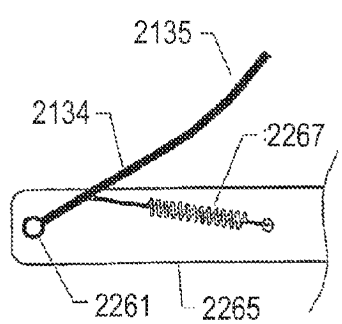

FIG. 26D

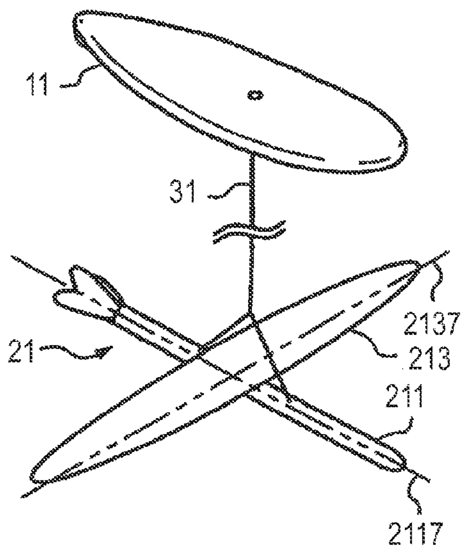

FIG. 27A

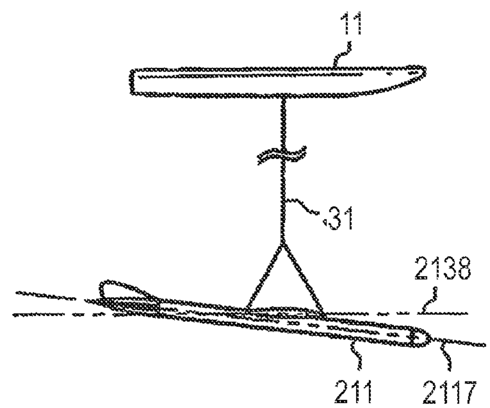

FIG. 27B

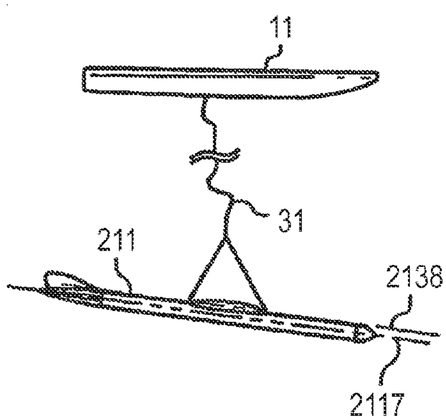

FIG. 27C

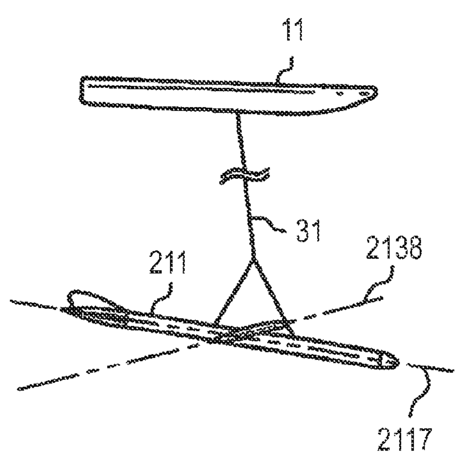

FIG. 27D

WAVE POWER

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 13/199,646, filed Sep. 6, 2011, now U.S. Pat. No. 8,376,790, which is a continuation of U.S. patent application Ser. No. 12/087,961, filed Feb. 2, 2009, now U.S. Pat. No. 8,043,133, which is a national phase entry lodged Jul. 18, 2008, under 35 U.S.C. §371 based on PCT Patent Application No. PCT/US 2007/001139, filed Jan. 18, 2007.

PCT Patent Application No. PCT/US 2007/001139 is a continuation-in-part of U.S. patent application Ser. No. 11/436,447, filed May 18, 2006, now U.S. Pat. No. 7,371,136, which claims priority from U.S. Provisional Patent Application No. 60/760,893, filed Jan. 20, 2006.

PCT Patent Application No. PCT/US 2007/001139 claims priority from the following U.S. patent applications:

U.S. Provisional Patent Application No. 60/841,834, filed Sep. 1, 2006;

U.S. patent application Ser. No. 11/436,447, filed May 18, 2006, now U.S. Pat. No. 7,371,136, which claims priority from U.S. Provisional Patent Application No. 60/760,893, filed Jan. 20, 2006; and

U.S. Provisional Patent Application No. 60/760,893, filed Jan. 20, 2006.

The entire disclosure of each of the above applications is incorporated herein by reference for all purposes.

BACKGROUND OF THE INVENTION

This invention relates to devices and methods which utilize the power of waves in water (hereinafter referred to as "wave power").

As a wave travels along the surface of water, it produces vertical motion, but no net horizontal motion, of water. The amplitude of the vertical motion decreases logarithmically with depth; at a depth of about half the wave length, there is little vertical motion. The speed of currents induced by wind also decreases sharply with depth. A number of proposals have been made to utilize wave power to do useful work. Reference may be made, for example, to U.S. Pat. Nos. 986,627, 1,315,267, 3,312,186, 3,453,981, 3,508,516, 3,845,733, 3,872,819, 3,928,967, 4,332,571, 4,371,347, 4,389,843, 4,598,547, 4,684,350, 4,842,560, 4,968,273, 5,084,630 and 6,561,856. The entire disclosure of each of those patents is incorporated herein by reference for all purposes.

SUMMARY OF THE INVENTION

In accordance with the present invention, we have discovered novel wave-powered devices, and novel methods using wave-powered devices. The invention will be chiefly described with reference to water vehicles which travel over the surface of the water when they are placed in water having waves moving across the surface of the water (hereinafter referred to as "wave-bearing water"). In such vehicles, at least part of the wave power moves the float over the surface of the water (the remainder of the wave power, if any, being converted into other useful forms, or wasted). However, the invention is also useful when the float is held in a fixed location, e.g., by an anchor or other attachment. In preferred embodiments, the invention makes it possible for unmanned water vehicles to carry out tasks which would be tedious, expensive or dangerous to carry out using vehicles operated by human beings.

In a first preferred aspect, this invention provides a novel wave-powered device which comprises (1) a float, (2) a swimmer, and (3) a tether connecting the float and the swimmer;

the float, swimmer and tether being such that, when the vehicle is in still water, (i) the float is on or near the surface of the water, (ii) the swimmer is submerged below the float, and (iii) the tether is under tension; and

the swimmer comprising

(2a) a swimmer body having a longitudinal axis, and

(2b) a fin system which (a) is secured to the body, (b) comprises a fin, and (c) when the device is in wave-bearing water,

(i) has a configuration which changes as a result of the wave motion, and

(ii) interacts with the water to generate forces which tend to move the swimmer in a direction having a horizontal component (hereinafter referred to simply as "in a horizontal direction").

The term "fin" is used herein to denote a component comprising a generally laminar surface against which, when the wave-powered device is in wave-bearing water, the water exerts pressure sufficient to substantially influence the movement of the swimmer. In many cases, the water vehicle includes two or more fins, which may be the same or different, secured to different points on the swimmer body. The "longitudinal axis" of the swimmer body lies in the generally vertical plane along which the swimmer moves when the device is in wave-bearing water.

The fin system preferably has at least one of (i.e., one or more of) the following characteristics:

(A) It comprises a fin, for example a generally laminar fin, which rotates about an axis of rotation (e.g., an axis of rotation generally transverse to the longitudinal axis of the swimmer body), the axis of rotation having a spatial relationship to the swimmer body which changes when the device is in wave-bearing water.

(B) It comprises (i) a fin, for example a generally laminar fin, which rotates about an axis of rotation (e.g., an axis of rotation generally transverse to the longitudinal axis of the swimmer body), and (ii) an elastic component (e.g., a metal coil spring, a metal leaf spring, a metal torsion bar, or an elastomeric component such as a natural or artificial rubber band) which is not part of the fin, and which deforms elastically and thus influences changes in the configuration of the fin system when the device is in wave-bearing water.

(C) It comprises a fin, for example a generally laminar and elastically deformable fin, having a leading edge which comprises (i) a relatively rigid central section which has a fixed spatial relationship with the swimmer body (including the possibility that the central section rotates about an axis of rotation having a fixed spatial relationship with the swimmer body), and (ii) relatively deformable outboard sections.

(D) It comprises two generally laminar fins, for example two generally laminar and elastically deformable fins which are mirror images of each other, and each of which rotates about an axis of rotation generally aligned with the longitudinal axis of the swimmer body (such fins operate in a manner similar to the pectoral fins on a fish or the wings on a bird, and are referred to herein as "pectoral" fins).

The tether preferably comprises one or both of the following characteristics:

(E) It comprises an elastically deformable member.

(F) It comprises a component which transmits data and/or electrical power.

The swimmer body preferably comprises one or more of the following characteristics:

(G) It comprises a substantially rigid fore section, a mid-section which is relatively flexible in the vertical plane, and a substantially rigid aft section, the tether being attached, for example, to the fore section, and the fin system being attached, for example, to the fore section.

(H) It comprises one or more components selected from electrical equipment, communications equipment, recording equipment, control electronics, steering equipment, and sensors.

(I) It comprises one or more substantially vertical fins which influence the orientation of the swimmer body in the horizontal plane. Such fins can help to balance the drag forces and to limit rotation of the swimmer when it is pulled sideways by the tether. In one embodiment, the swimmer body comprises a fixed leading fin and a trailing fin which can be actuated to steer the swimmer. In a similar embodiment, a part of the swimmer body has a relatively small horizontal dimension and a relatively large vertical dimension; for example, such a part, if at the trailing end of the swimmer body, could be actuated to steer the swimmer.

(J) It comprises a generally tubular housing, with pectoral fins which extend either side of the body;

When reference is made herein to a fin or other component which rotates about an axis of rotation, or to a component which is rotatably mounted or rotatably secured, this includes not only the possibility that the rotation is about a single axis, but also the possibility that the rotation results from rotation about two or more axes (which may be, but need not be, parallel to each other), and the possibility that the rotation involves a continuous relative motion of adjacent parts of the fin or other component, as for example when one part of a flexible fin is fixed and the rest of the flexible fin moves relative to (i.e., “rotates about”) the fixed part.

In a second preferred aspect, this invention provides a wave-powered water vehicle which comprises (1) a float, (2) a swimmer, (3) a tether connecting the float and the swimmer, and (4) a computer system;

the float, swimmer and tether being such that, when the vehicle is in still water,

(i) the float is on or near the surface of the water,

(ii) the swimmer is submerged below the float, and (iii) the tether is under tension; the swimmer, when the vehicle is in wave-bearing water, interacting with the water to generate forces which move the vehicle in a horizontal direction;

the float comprising a satellite-referenced position sensor;

the swimmer comprising (a) a sensor which senses direction in a horizontal plane, and (b) a steering actuator; and

the computer system (a) being linked to the position sensor, the horizontal sensor and the rudder, and (b) containing, or being programmable to contain, instructions to control the steering actuator in response to signals received from the position sensor and the horizontal sensor, or in response to signals received from a sensor on the vehicle. In the water vehicles of the second aspect of the invention, the swimmer preferably comprises a body and a fin system according to the first aspect of the invention, but can comprise a different means for generating forces which move the vehicle in a horizontal direction.

The water vehicles of the invention often comprise a single float and a single swimmer, and the invention will be chiefly described with reference to such water vehicles. However, the invention includes the possibility that there is more than one float, and/or more than one swimmer, for example a single float attached to a plurality of swimmers, the swimmers preferably being axially aligned, by a plurality of tethers.

In a third preferred aspect, this invention provides a method of utilizing wave power which comprises placing a device according to the first or second preferred aspect of the invention in a body of water which has or which is expected to have water waves traveling across its surface.

In a fourth preferred aspect, this invention provides a method of obtaining information which comprises receiving signals from a device according to the first or second preferred aspect of the invention, for example signals from some or all of a plurality of such devices, for example 2-10,000 or 10-1000 devices.

In a fifth preferred aspect, this invention provides a method of obtaining information which comprises examining signals recorded by a device according to the first or second preferred aspect of the invention, for example signals recorded by some or all of a plurality of such devices, for example 2-10,000 or 10-1000 devices.

In a sixth preferred aspect, this invention provides a method for controlling a function of a device according to the first or second preferred aspect of the invention, the method comprising sending signals to the device.

n a seventh preferred aspect, this invention provides novel floats suitable for use in the first or second preferred aspect of the invention and for other purposes; novel swimmers suitable for use in the first or second preferred aspect of the invention and for other purposes; novel fin systems suitable for use in the first or second preferred aspect of the invention and for other purposes; and novel fins suitable for use in the first and second preferred aspects of the invention and for other purposes.

In an eighth preferred aspect, this invention provides kits of parts comprising two or more of the components needed to assemble a device according to the first or second preferred aspect of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is illustrated by the accompanying drawings, which are diagrammatic and not to scale;

FIG. **1** is a diagram of a water vehicle;

FIGS. **2** and **3** are cross-sections of fins for use in certain embodiments;

FIG. **4** is a cross-section of a tether;

FIG. **5** is a block diagram of a control system;

FIG. **6** shows a path for a station-keeping water vehicle;

FIG. **7** is a perspective view of a water vehicle;

FIG. **8** shows different configurations of a fin in FIG. **7**;

FIG. **9** is a perspective view of a water vehicle;

FIG. **10** is an enlarged perspective view of part of FIG. **9**;

FIGS. **11**A to **11**D show different configurations of the fins in FIG. **9**;

FIGS. **12-19** and **21** are side views of water vehicles;

FIG. **20** is a plan view of the water vehicle of FIG. **21**;

FIGS. **22**A to **22**C show different configurations of a water vehicle having a flexible body;

FIGS. **23-25** are perspective views of water vehicles;

FIGS. **26**A to **26**D show different views of a water vehicle; and

FIGS. **27**A to **27**D show different views of a water vehicle.

In some Figures, the fin system is numbered 0, 1, 2, 3 or 4. If the configuration is numbered 0, it is the configuration likely to be adopted when the vehicle is in still water. If the configuration is numbered 1, it is the configuration likely to be adopted when float is falling behind the wave crest, and the tension on the tether is falling (and may be zero). If the configuration is numbered 2, it is the configuration likely to be adopted when the float has fallen to the trough of the wave, and the tension on the tether starts to increase. If the configuration is numbered 3, it is the configuration likely to be adopted when the float is rising towards the top of a wave and the tether is at or close to its maximum tension for this particular cycle. If the configuration is numbered 4, it is the configuration likely to be adopted when the float is near the top of a wave crest and the tension on the tether has decreased. It is to be understood, however, that the configuration of the fin system in practice will not necessarily be that shown in the Figures.

DETAILED DESCRIPTION OF THE INVENTION

In the Summary of the Invention above, the Detailed Description of the Invention below, and the accompanying drawings, reference is made to particular features of the invention. It is to be understood that the disclosure of the invention in this specification includes all possible combinations of such particular features. For example, where a particular feature is disclosed in the context of a particular aspect, a particular embodiment, or a particular Figure, that feature can also be used, to the extent appropriate, in the context of other particular aspects, embodiments and Figures, and in the invention generally. It is also to be understood that this invention includes all novel features disclosed herein and is not limited to the preferred aspects of the invention set out above.

The term “comprises” and grammatical equivalents thereof are used herein to mean that other elements (i.e., components, ingredients, steps etc.) are optionally present. For example, a water vehicle “comprising” (or “which comprises”) components A, B and C can contain only components A, B and C, or can contain not only components A, B and C but also one or more other components.

The term “at least” followed by a number is used herein to denote the start of a range beginning with that number (which may be a range having an upper limit or no upper limit, depending on the variable being defined). For example “at least 1” means 1 or more than 1, and “at least 80%” means 80% or more than 80%.

The term “at most” followed by a number is used herein to denote the end of a range ending with that number (which may be a range having 1 or 0 as its lower limit, or a range having no lower limit, depending upon the variable being defined). For example, “at most 4” means 4 or less than 4, and “at most 40%” means 40% or less than 40%.

When, in this specification, a range is given as “(a first number) to (a second number)” or “(a first number)–(a second number)”, this means a range whose lower limit is the first number and whose upper limit is the second number. For example, “from 5 to 15 feet” or “5-15 feet” means a range whose lower limit is 5 feet and whose upper limit is 15 feet.

The terms “plural”, “multiple”, “plurality” and “multiplicity” are used herein to denote two or more than two items.

Where reference is made herein to a method comprising two or more defined steps, the defined steps can be carried out in any order or simultaneously (except where the context excludes that possibility), and the method can optionally include one or more other steps which are carried out before any of the defined steps, between two of the defined steps, or after all the defined steps (except where the context excludes that possibility).

Where reference is made herein to “first” and “second” elements, this is generally done for identification purposes; unless the context requires otherwise, the first and second elements can be the same or different, and reference to a first element does not mean that a second element is necessarily present (though it may be present).

Where reference is made herein to “a” or “an” element, this does not exclude the possibility that there are two or more such elements (except where the context excludes that possibility). For example, where reference is made herein to a fin, or a fin system, the swimmer can (and frequently does) comprise two or more fins or fin systems, which may be the same or different.

Where reference is made herein to two or more elements, this does not exclude the possibility that the two or more elements are replaced by a lesser number or greater number of elements providing the same function (except where the context excludes that possibility). For example, the swimmer body and the fin system can together form a single unitary body. The numbers given herein should be construed with the latitude appropriate to their context and expression; for example, each number is subject to variation which depends on the accuracy with which it can be measured by methods conventionally used by those skilled in the art.

Unless otherwise noted, the references to the positioning and shape of a component of the vehicle refer to that positioning and shape when the vehicle is in still water. Various terms are used in this specification in accordance with the definitions given above and the further definitions given below.

“Leading edge” (or leading end) and “trailing edge” (or trailing end) denote the front and rear surfaces respectively of a fin or other component as wave power causes the vehicle to move forward.

“Fore” and “aft” denote locations relatively near the leading and trailing edges (or ends) respectively.

“Aligned” denotes a direction which lies generally in a vertical plane which is parallel to the vertical plane which includes the longitudinal axis of the swimmer. “Axially aligned” denotes a direction which lies generally in the vertical plane which includes the longitudinal axis of the swimmer.

“Transverse” denotes a direction which lies generally in a vertical plane orthogonal to the vertical plane which includes the axial centerline of the swimmer.

Where reference is made herein to a feature which “generally” complies with a particular definition, for example “generally in a vertical plane”, “generally laminar”, or “generally horizontal”, it is to be understood that the feature need not comply strictly with that particular definition, but rather can depart from that strict definition by an amount which permits effective operation in accordance with the principles of the invention.

All the components of the vehicle, particularly any electrical connections, are preferably constructed of materials which are resistant to salt water, and/or enclosed within a watertight jacket of such material. Preferably, the materials which are exposed to the water are resistant to bio-fouling, and are unattractive or even repellent to marine animals, e.g., sharks. Suitable materials can for example be selected from metals and polymeric compositions, including copper-containing paints and low surface energy polymers such as polytetrafluoroethylene. When the vehicle includes batteries and solar panels (or other electricity-generating means), bio-fouling can also be discouraged by using the power from the batteries or solar panels to briefly electrify conductive materials on the vehicle, and/or to energize a vibrator which will dislodge bio-fouling materials. Leading edges which may be snagged by seaweed can optionally have sharp or serrated edges.

The vehicle is preferably designed to minimize drag as movement of the swimmer pulls it forward, and to minimize the effect of winds and water currents which move the vehicle sideways. The float or the swimmer or both can have flaps which are folded-in and have little effect on drag when the float or swimmer is moving forward, but which fan out and increase drag when the float or swimmer is moving backwards. Such flaps are preferably positioned so that they keep the float and/or the swimmer in a desired orientation if it moves backwards.

A preferred device having characteristic (B) above can for example include a fin system which comprises (1) a plurality of fins, for example 3-10 or 4-6 fins, e.g., 5 fins, (2) a rigid bar which is mounted on the swimmer body, and to which each of the fins is rotatably mounted, and (3) an elastic component as defined in (B). The rigid bar is preferably aligned with the longitudinal axis of the swimmer body. The fins, which can be the same or different, preferably lie behind each other (optionally in the same horizontal plane), and preferably each of the fins rotates about a transverse axis which is generally transverse to the longitudinal axis of the swimmer body. Each of the elastic components influences the speed and/or the extent of the rotation of the fin to which it is linked. The elastic component can for example extend from a fixed point on the rigid bar, for example aft of the transverse axis of the fin, to a fixed point on the fin, for example aft of the transverse axis of the fin.

A preferred device having characteristics (A) and (B) above can for example include (i) a generally laminar fin which is mounted, optionally rotatably mounted, directly or indirectly on a rigid bar which is mounted, optionally rotationally mounted, on the swimmer body, and (ii) a spring and/or a torsion bar which is directly or indirectly connected to the fin and/or to the rigid bar and which influences (a) the speed and/or the extent of the rotation of the fin and/or the rigid bar, and/or (b) the spatial relationship between the swimmer body and the axis of rotation, during part or all of the changes in configuration of the system.

A preferred device having characteristic (C) above can for example have a fin system which comprises a generally laminar and elastically deformable fin (such a fin optionally being the sole elastic component, or one of a plurality of elastic components, of the fin system), the fin having a leading edge which comprises (i) a relatively rigid central section which rotates about an axis of rotation generally transverse to the longitudinal axis of the swimmer body, and (ii) relatively deformable outboard sections (for example a fin having a swept back, e.g., generally V-shaped, leading edge),

The Swimmer Body

The swimmer body often has a generally cylindrical shape, or other shape selected to minimize drag as the fin system pulls the swimmer through the water. Often there is a single swimmer body, but there can be a plurality of bodies secured to each other, preferably rigidly, with their axes aligned, or with their axes parallel to, and spaced-apart from, each other. Preferably the body has a longitudinal axis which is generally horizontal when the vehicle is in still water.

Usually, but not necessarily, the swimmer body has a length (i.e., the dimension measured along the longitudinal axis) substantially greater than its width (i.e., the dimension of the swimmer body measured transverse to the longitudinal axis). The length of the swimmer body can for example be at least 1 foot (0.3 m), e.g., 3 to 10 feet (0.9 to 3 m) or 4 to 6 feet (1.2 to 1.9 m), but can be substantially greater, e.g., up to 1000 feet (300 m) or more. The diameter (or, for non-cylindrical bodies, each of the minimum and maximum transverse dimensions) of the swimmer can for example be at least 0.1 feet (30 mm), or at least 0.3 feet (90 m), up to, for example, 0.1 times the length of the swimmer.

In some embodiments the entire swimmer body will be rigid. However, it is also possible for part of the swimmer body to be elastically deformable. For example, the swimmer body can have a central section which is flexible, preferably substantially only in the vertical plane, with the rudder mounted on a rigid section aft of the flexible central section and the fin system mounted on a rigid section forward of the flexible central section. Optionally, the swimmer has a center of buoyancy which is above the center of gravity.

As further discussed below, a wide variety of additional components can be attached to the swimmer body. Heavy components are preferably secured to the swimmer rather than to the float. The wet weight of the swimmer, including the components attached thereto, can for example be 5-20,000 lbs (2-9,000 kg), e.g., 5-500 lbs (2-225 kg), for example 20-60 lbs (9-30 kg). Many components are preferably placed within a watertight enclosure provided by the swimmer body (for example electrical equipment, including batteries, electronic equipment, servo mechanisms, watertight pass-throughs, and direction-finding equipment). Others are preferably or necessarily placed outside the swimmer body, for example stabilizer fins, stabilizer weights, rudders, some types of sensor, and sample collectors.

Stabilizer fins, which can for example be placed near the front and/or near the rear of the swimmer body, can for example be generally vertical fixed and aligned fins which resist transverse drag on the swimmer, or generally horizontal fixed and aligned fins which resist vertical drag on the swimmer. Stabilizer weights can for example be bars and/or discs, usually aligned with the swimmer body, fixed to struts descending vertically from the swimmer body, thus increasing the weight and changing the center of gravity of the swimmer, or can be part of a keel-like vertical stabilizer fin.

In one embodiment, a hydrophone is secured to the swimmer body. Preferably, in order to separate the hydrophone from noise generated by the swimmer, the hydrophone is placed at the end of a cable dragged behind the swimmer body, or on an extension bar projecting from, e.g., from the front of, the swimmer body.

The Float

The float can be of any convenient size and shape, bearing in mind the components which it carries, the way in which it will be used, and the desirability of minimizing drag in the water and against wind. The length of the float can be less than, e.g., 0.5 to 0.9 times, substantially equal to, e.g., 0.9 to 1.1 times, or greater than, e.g., 1.1 to 4 times, the length of the swimmer. The length of the float can for example be at least 1 foot (0.3 m), e.g., 3 to 10 feet (1-3 m) or 4 to 6 feet (1.2-1.9 m), but can be substantially greater, e.g., up to 1000 feet (300 m) or more, so long as it is not too large to be substantially moved by waves. The breadth of the float can for example be at least 0.3 foot (1 m), or at least 2 feet (1.9 m), up to, for example, 0.3 times the length of the float. Optionally, the float has a center of buoyancy which is above the center of gravity. The float can for example have 20-500 lbs (9-225 kg, e.g., about 80 lbs (36 kg), of buoyancy, and/or a buoyancy which is 2-4 times the wet weight of the swimmer.

To reduce the danger that wind, waves or current forces push the float sideways, preferably both the center of water drag and the center of wind drag are behind the line attachment point, since this helps to keep the float in a head-on orientation in which it has the lowest overall drag. Wind and water forces acting on the parts of the float forward of the tether attachment point tend to rotate the float away from the desired orientation, whereas those aft of the attachment point tend to produce the desired orientation. Therefore, the nose of the float is preferably is relatively blunt and truncated, whereas the tail portion of the float preferably has an extended tail portion with greater vertical surface area.

The float may include a rudder. The rudder may be fixed during some or all of the operation of the vehicle, in order to keep the center of drag behind the tether attachment point. The rudder may also be adjustable, in order to assist steering of the vehicle; in this case, the tether is preferably attached to the swimmer in front of the swimmer's center of drag. Especially when the tether is attached slightly forward of the center of buoyancy of the float, the submerged surfaces of the float may be shaped so as to produce forward thrust.

The float optionally comprises an outer shell comprising a polymeric composition, e.g., a fiberglass- or carbon fiber-reinforced polymeric composition, and/or a thick-walled elastomeric sheet material. The shell can optionally surround a closed cell polymeric foam core, e.g., a compliant closed cell foam, and/or a plurality of hollow cavities. In some embodiments, such cavities can optionally be inflatable (for example being composed of an elastomeric material), so that they can be partially or completely filled with water and/or air to control buoyancy.

The Tether

The tether connects the float and the swimmer mechanically, and for this purpose comprises a tensile member of suitable breaking strength, e.g., at least 500 lb (225 kg) or at least 1500 lb (675 kg). The tensile member can for example be composed of a metal, e.g., stainless steel, and/or a polymeric composition, e.g., Kevlar or Spectra. Often, the tether also comprises one or more members which do not carry any load and which transmit electrical power and/or data, e.g., one or more twisted pairs of insulated electrical conductors, optical fibers or acoustic cables. Generally, the tether will support only tensile loads, but the invention includes the possibility that the tether will also resist compression, e.g., is a rod.

To reduce drag, the components of the tether are preferably arranged to minimize the area of the leading edge of the tether, with the primary tensile member at the front. Thus, the tether optionally includes a jacket, preferably of streamlined cross-section, e.g., composed of a polymeric composition, e.g., a composition based on a silicone or vinyl chloride polymer, which surrounds the other components. Twisting of the tether increases drag, and optionally measures can be taken to reduce twisting. For example, a second tensile member can be present at the trailing edge of the tether, and/or the vehicle can include a device to detect and correct twisting of the tether, and/or the vehicle can be directed along a path in which the clockwise and anticlockwise turns are balanced (in particular, when the vehicle is directed along a path surrounding a fixed point).

The tether can for example have an aligned dimension of 0.5 to 1.0 inch (13-25 mm), e.g., about 0.625 inch (16 mm, a transverse dimension of 0.125 to 0.5 inch (3 to 13 m), e.g., about 0.19 inch (5 mm, and a length of for example 10 to 80 feet (3-25 m), e.g., 17 to 23 feet (5-7 m). Either the float or the swimmer can include a reel or other equipment which makes it possible to change the length of the tether, either to suit particular wave conditions and/or water depth, and/or to make the vehicle more easily stored, carried and deployed.

The tether can for example include an elastomeric member, e.g., a spring, which changes in length reversibly when the relative positions of the float and swimmer change. For example, one leg of a tether generally shaped as an inverted Y can comprise such an elastomeric member.

In some embodiments, there is a single tether. The tether can for example have a central section which is a single line, and a lower section (attached to the swimmer) and/or an upper section (attached to the float) which has two or more legs, secured to fore and aft positions, or to transverse positions, on the swimmer or the float. In one embodiment, the tether has the shape of an inverted Y, the lower legs of the Y being (a) aligned with, and secured to fore and aft positions on, the swimmer, or (b) transverse to the swimmer and secured to components extending transversely from the axis of the swimmer.

When there is a single tether between the swimmer and the float, its configuration and point of attachment (or points of attachment, if the tether has two or more lower legs) to the swimmer are preferably such that the upward force exerted on the swimmer, when the tether is pulled upwards, passes through the swimmer at or close to the center of gravity of the swimmer. The swimmer is then substantially horizontal when the vehicle is in still water. This assists the swimmer to maintain a level orientation.

When there is a single tether between the swimmer and the float, its configuration and point of attachment (or points of attachment, if the tether has two or more upper legs) to the float are preferably such that the downward force exerted on the float, when the tether is pulled upwards, passes through the float near, or slightly forward of, the center of buoyancy of the float.

In other embodiments, there are multiple tethers, for example first and second tethers respectively attached to fore and aft positions on the float and the swimmer. Multiple tethers increase drag, but reduce twisting.

The tension force of the tether stabilizes both the swimmer and the float. While each element may also be independently stabilized by positioning of the center of flotation above the center of gravity, this is not necessary. The fact that the line tension stabilizes both the swimmer and float simplifies the control of the vehicle. In some embodiments, the vehicle only needs to be steered in one degree of freedom, and other attitude control is passively stabilized, making it unnecessary for the vehicle to include attitude control thrusters or flaps (although such thrusters and flaps can be present).

The Fin Systems

When the swimmer is being moved by wave power, the configuration of the fin system changes in cycles corresponding to the waves on the surface of the water. Generally, but not necessarily, the changes in the configuration in each cycle are substantially the same. The changes in the configuration in each cycle are generally substantially continuous, but can be discontinuous (i.e., there can be one or more periods in each cycle during which the configuration remains the same). During at least part of the cycle, the fin system interacts with the water to generate forces which thrust the swimmer in a horizontal direction. In some embodiments, the fin system comprises a fin which rotates about a transverse axis. In other embodiments, the fin system comprises a pair of fins which rotate about a longitudinal axis. In either case, as the swimmer rises and falls, the fin or fins can optionally undergo elastic distortion which enhances the forward thrust of the swimmer.

Different wave sizes will produce different responses from different fin systems. For example, with relatively large waves, the majority of the thrust often tends to be produced during the upward and downward phases of fin motion, whereas with relatively small waves, the majority of thrust tends to result from rotation of the fins. Flexible fins tend to produce thrust from both small and large waves.

For any particular water vehicle of the invention, the influence of the swimmer on the movement of the float will depend in part on the size and frequency of waves. The movement of the float will also depend for example on environmental conditions such as water currents and wind, and any other propulsion or steering system operating on the float. In suitable conditions, the swimmer will move the vehicle forward at a speed which is satisfactory for many purposes, without any other propulsion system (though it may be desirable to use another power source to operate a steering system).

The horizontal motion of the swimmer and float will often be cyclic, alternating between a glide phase and a kite phase, the float's peak horizontal speed being during kite phase, and the swimmer's peak horizontal speed being during the glide phase.

In the glide phase, the line tension is low and the swimmer is able to glide forward rapidly. The float may move forward slowly or not move forward. During the kite phase, the line tension is high and, if the swimmer was successful at gliding forward during the glide phase, the line will be at an angle such that the increased tension slows the forward motion of the swimmer. The steep line angle and high tension will pull the float forward rapidly, partially catching up with the advance the swimmer made during the glide phase.

Drag is proportional to the square of velocity. Since velocity of the swimmer is highest during the glide phase it is preferred to minimize drag in this phase. Described below and in the attached FIGS. **27**A-D is one example of a water vehicle which achieves low drag during glide phase and is able to transition from kite phase to glide phase quickly and quietly. In this example, the swimmer body has a central body structure that is longest along a longitudinal axis. Fins extend from either side of the body and can rotate relative to the body about an axis that is substantially perpendicular to the body longitudinal axis and preferably also to the tether axis. There may be one pair of wings with a single axis, or multiple wing pairs. Preferably, the rotation of the fins is controlled in part by a spring which will resist rotation in either direction from a rest position. One advantage of using such a spring is that it provides gently increasing resistance to rotation without producing the noise that results from sudden stops and which can prejudice the operation of sensitive acoustic instruments.

While the vehicle is at rest in still water, the tether is preferably generally vertical and is attached to the body so that the axis of the body is as an angle of zero to 30°, preferably 3-10°, to the horizontal. The chord axis of the fin in the rest position is preferably generally horizontal.

When the line tension is released by the float moving down, the swimmer will move down and the fluid pressure on the wing will cause it to rotate to a glide position, while the spring resists this rotation. The spring force and the lift force are balanced such that the angle of the wing in glide position is similar to the body longitudinal axis and thus provides minimum drag. When the line tension is increased by the float moving up, the swimmer will move up and the fluid pressure on the wing will cause it to rotate to a kite position, while the spring resists this rotation. The spring force and the lift force are balanced such that the wing operates at an efficient angle of attack during the kite motion to produce forward thrust.

One example of an efficient wing shape for gliding has high aspect ratio (span/chord), an elliptical plan form, and a slender airfoil shape. A fin with a relatively short chord enables rapid rotations between glide angle and kite angle so that the fin can achieve optimal angle of attack for each phase with minimum lost motion.

A single fin is shown in FIG. **27**. Multiple fins are similarly possible, with each fin behaving in a similar manner. In addition to the primary thrust producing wing or wings, smaller tail wings or front canard wings may be provided for stability.

Controlling Angle of Glide

The optimum glide angle will vary depending on the sea state. If wind or surface currents are pulling the float backwards, then a steep glide angle may be needed to achieve forward motion. Conversely, if the winds and currents are favorable, then a shallow glide angle can increase distance traveled each glide cycle.

Active control may be applied to the angle of a tail wing or canard wing to control the glide angle. Alternatively, or in addition, the center of gravity may be adjusted along the body axis by moving an internal mass. For example a lead screw drive may move the battery pack fore or aft to adjust the center of gravity. Alternatively or additionally, the tether attachment may be adjusted to affect the body angle.

In preferred embodiments, the vehicle is equipped with control and steering systems which enable it to be remotely controlled in a desired way, for example so as to move in a closed pattern around a desired fixed location, and/or to follow a desired path between two locations, which may be many miles apart, and/or to traverse slowly back and forth over an area of the ocean in order to gather a wide variety of data.

If the float is also moved by other forces (for example by wind, water currents or a conventional propulsion system) the movement of the swimmer modifies (for example accelerates or decelerates and/or changes the direction of) the movement of the float.

Different fin systems which interact with the water in the desired way include, but are not limited to, the various types described herein. A particular fin system can make use of combinations of two or more of these types, except when they are incompatible with each other; and a water vehicle can comprise two or more fin systems of the same or different types or combinations of types. Where reference is made below to a "generally laminar fin", this includes the possibility that the thickness of the fin changes, regularly or irregularly, in the transverse direction or in the aligned direction, or both, and the possibility that parts of the fin extend outwards from its generally laminar shape. For example, at least part of a fin can have an airfoil cross section, i.e., a cross-section such that the fin produces lift and drag as it interacts with the wave-bearing water Where reference is made below to a generally laminar fin which "lies in a generally horizontal plane", this includes the possibility that the principal plane of the fin lies in a plane which is inclined to the horizontal at an angle which permits effective operation of the fin, for example at an angle which is not more than 45°, preferably not more than 20°, to the horizontal.

In some embodiments of the invention, part or all of the fin system has a first configuration when the vehicle is in still water; is converted from the first configuration into a second configuration when the swimmer is pulled upwards by the tether as a result of a wavecrest lifting the float upwards; and is converted from the second configuration into a third configuration when the swimmer sinks downwards as a result of a wavetrough allowing the float to descend. The third configuration will generally be different from the first configuration, but the invention includes the possibility that it is the same as the first configuration. When the fin system is converted from the second configuration to the third configuration, it can, but need not, pass through the first configuration as a transitory state.

The fin system can for example comprise one or more fins comprising generally laminar portions which deform elastically between the different configurations. Alternatively or additionally, the fin system can for example comprise one or more elastically deformable components, which change shape between the different configurations, and thus control, or help to control, the movement of fin or fins comprising generally laminar portions. The elastically deformable component can control, or help to control, the movement of a fin in one direction only (e.g., a spring) or in two or more directions, e.g., in both the upward and downward direction (e.g., a torsion bar).

Limit stops may be included to prevent undesired movement of a fin, for example to prevent excessive bending of a flexible fin. The stop may be a rigid stop, an elastic stop, e.g., a spring, including an increasing rate spring

The fin system comprises at least one fin, the fin preferably having one or more of the following characteristics:

(a) It is at least in part elastically deformable.

(b) It is at least in part substantially rigid.

(c) It comprises a leading portion which is relatively rigid and a central portion and/or a trailing portion which is relatively and elastically deformable.

(d) It comprises a leading portion which is relatively and elastically deformable, a central portion which is relatively rigid, and a trailing portion which is relatively and elastically deformable.

(e) It has a shape similar to the shape of the tail of a fish or a whale.

(f) In the first configuration, it is generally planar in a generally horizontal plane.

(g) In the second configuration, it is generally laminar and downwardly curving, the second configuration being a result of flexing and/or rotating the fin about an axis which lies in a plane which is generally orthogonal to the tether and generally at right angles to the longitudinal axis of the swimmer.

(h) When the swimmer sinks downwards as a result of a wavetrough causing the float to fall, the fin system changes from the second configuration to the third configuration, the third configuration being generally laminar and upwardly curving.

Other optional features of the fin system include:

(1) It comprises a plurality of fins, which may be the same or different, and which may be aligned in the same horizontal plane, or which may be in two or more different planes.

(2) It comprises a plurality of fins which are mounted to a frame, for example a plurality of fins mounted to both sides of an axially aligned spine, or a plurality of fins mounted between aligned side rails.

(3) It comprises a pair of fins, the fins

 (i) extending away from opposite sides of the swimmer body,

 (ii) being secured to the swimmer body so that they can move between the first and second configurations, the position of the fins in the second configuration extending upwards relative to the position of the fins in the first configuration, and

 (iv) being biased by a spring or other elastic recovery means into the first configuration and away from the second configuration.

(4) The fin system comprises a pair of fins and the tether comprises an inverted V-shaped section having two legs, each leg being secured to one of the fins; and

(5) It comprises a caudal fin.

In the first aspect of the invention, the fin system optionally comprises at least one additional member whose shape is fixed and is such that that the additional member directly or indirectly generates desired horizontal forces as the swimmer is moved by the movement of the float. In one embodiment of the second aspect of the invention, such members are the sole means for generating the desired forces.

The optimum amount of flexibility for a flexible fin will depend on many characteristics of the design and of the wave characteristics anticipated. If the fin is too flexible, then the curvature during the large amplitude motion may be so large that the trailing portion of the fin may flex to be parallel to the direction of motion and thus generate little thrust. If the fin is too rigid, then the fin will not flex with any inflections and small amplitude inputs will not efficiently generate thrust. Those skilled in the art will have no difficulty, having regard to their own knowledge and the information contained in this specification, in determining a suitable amount of flexibility.

The fin system often includes a rigid component which is secured to, preferably positioned above, the body of the swimmer. The rigid component can for example have one or more of the following characteristics:

(i) It is rigidly fixed to the body portion.

(ii) It is positioned above the body portion and a unitary tether, or one leg of a tether having an inverted Y configuration, is secured thereto.

(iii) At least one fin system is secured thereto. When there is more than one fin system, the systems can be mounted one above the other and/or beside each other.

(iv) It is the first component of a support system which also comprises a second rigid component. The first component is positioned above, and secured directly to, the body portion in a generally vertical plane and the second component is secured directly to the first component and has one or more fin systems secured thereto. The second component is optionally secured to the first component so that it can rotate relative to the first component in a generally vertical plane, and the rotation can optionally be influenced by an elastically recoverable member, e.g., a spring or a torsion bar. At least part of the tether is optionally secured to the second component so that upward pulling of the tether distorts the elastically recoverable member. The extent of rotation is optionally further limited by an inextensible member.

Water Vehicles with Pectoral Fins

In some embodiments, a generally planar fin or a pair of generally planar fins undergoes elastic deformation in the transverse direction (and may also undergo elastic deformation in the aligned direction). In some cases, such fins can move vertically without substantial vertical motion of the swimmer body. They flap in a manner similar to the pectoral fins on a fish, or the wings on a bird. Preferably the pectoral fin or fins rotate about an axially aligned longitudinal axis. Optionally, the pectoral fin surfaces can also rotate and/or flex relative to the horizontal plane or relative to a plane that intersects the longitudinal axis and an axis through the wing spar.

Pectoral fins of this kind are preferably directly actuated by the tether, thus reducing motion of the swimmer body. In some cases, this makes them well suited for large swimmers or for applications where the swimmer body should be held relatively steady.

By attaching the legs of the tether to different points along the length of the pectoral fins, the amount of fin motion relative to the amount of line motion may be adjusted.

Pectoral fins may for example have an internal skeletal structure made of a less flexible, optionally substantially rigid, material with high fatigue life such as tempered steel or carbon fiber composite. The skeletal structure can include a front spar that makes the leading edge relatively rigid. The primary flexion of the skeletal structure occurs in vertical bending of the front spar near the attachment to the body. The rigidity of the front spar may increase toward the outer parts to prevent the wing tips from drooping. The trailing edge of the wing can for example be comprised only of the elastomer jacket material and be relatively flexible.

The tether is preferably attached to the pectoral wings at two points, one on each wing. The wing structure is preferably such that when the tether is not under tension, the fin flexes downward; and when the vehicle is in still water, the fins flex to a relatively flat position. Increased line tension will cause the wings to flex upward. The line attachment points are preferably toward the front edge of the pectoral wings. The center of gravity (COG) is preferably under the line junction point so that the swimmer body is horizontal in still water. If there is more fin area behind the line attachment, upward motion will cause the swimmer to pitch nose up. If there is more fin area is behind the COG, downward motion will cause the swimmer to pitch nose down. Optionally, a rudder steers the swimmer. Optional features of devices having pectoral wings can include:

(a) A smooth outer body which has no exposed mechanism and is resistant to fouling.

(b) Flexion distributed over a large area so that fatigue at specific points can be minimized for long life.

(c) A streamlined overall shape which enables increased speed.

(d) Sudden increases in tether tension are transmitted immediately to fins so that the inertia of the vehicle does not impeded conversion to thrust.

(e) The tips of the fins extend beyond the line attachment points and the wing spar is relatively rigid in this region, so that the tips of the fins move through a larger amplitude than the tether. This helps generate large amounts of thrust from small amounts of tether motion.

Additional Components.

Additional components which can be part of the water vehicle include, but are not limited to, those described in paragraphs 1-14 below. Some components, e.g., electronic control equipment, can be part of either or both of the float and the swimmer. Bulky or massive items, e.g., batteries, and equipment that operates best with limited motion and/or when protected from wind and noise, such as imaging or mapping equipment, and hydrophones and sonar equipment, are preferably part of the swimmer. Other components, e.g., solar collection means, radio and navigation antenna, beacons and weather sensors are preferably part of the float.

(1) Communications equipment for sending and/or receiving data, e.g., digital or analog radio signals, for example communications equipment for

(i) sending signals which reflect data collected by a monitoring or sensing device which is part of the vehicle;

(ii) receiving signals, e.g., commands, from a base station (e.g., a ship or a ground station) or from navigation devices, for example satellite navigation equipment such as a global positioning satellite (GPS), or sonar or radio buoys,

(iii) sending signals to a receiving station, for example via a satellite,

(iv) sending signals which are influenced by the location of the vehicle.

(2) Recording equipment for recording signals, e.g., digital or analog signals, for example signals which are

(i) influenced by signals from a satellite navigation system, e.g., GPS;

(ii) sent from the vehicle to a receiving station, for example via a satellite;

(iii) influenced by the location of the vehicle; or

(iv) influenced by a sensor which is part of the vehicle, e.g., a hydrophone attached to the swimmer;

(3) Control electronics for controlling equipment forming part of the vehicle.

(4) Steering means, for example a rudder forming part of the float and/or a rudder forming part of the swimmer, the steering means being for example a fixed rudder on the float (e.g., to keep the center of drag behind the point at which the tether is attached to the float), and/or a rudder or other steering means which is attached to the swimmer and which includes a rudder actuator responsive to signals generated within the vehicle, e.g., from a magnetic compass or a gyroscope, and/or received by communications equipment forming part of the vehicle.

(5) Electrical power sources, for example batteries or fuel cells, preferably power sources that can be recharged, for example by output from solar cells mounted on the float. Batteries, because they are heavy, are preferably placed within the container body of the swimmer. There can be, for example, four to ten 6 volt lead acid batteries.

(6) Means for utilizing solar energy, e.g., solar panels or solar cells mounted on the float.

(7) A sensor, this term being used to denote any device which reports, or responds to a change in, any observable condition. Thus the sensor can be any one of a large variety of scientific or surveillance devices, for example a compass, a gyroscope, a temperature sensor, a pressure sensor, a sensor of any type of electromagnetic radiation, e.g., visible, ultraviolet or infrared light, a chemical sensor, e.g., a salinity sensor, a magnetometer, a biological sensor, a geological sensor, a water current sensor, a depth sensor, a speedometer, equipment for imaging the sea floor, a sensor of weather or other climatic changes, e.g., windspeed, rainfall, or barometric pressure, or a hydrophone (for example a hydrophone for monitoring the sounds made by whales or other aquatic life).

In some embodiments, because the vehicles of the invention do not need to include conventional propulsion components, or other noisy components, they provide excellent platforms for noise-sensitive devices and do not have any adverse effect on noise-sensitive devices carried by other equipment, e.g., other water vehicles.

(8) Auxiliary propulsion means, e.g., a motor-driven thruster.

(9) Auxiliary attitude control means, e.g., flaps.

(10) Means for reversibly altering the buoyancy of the float. Such means include, for example, chambers which can be inflated with air to increase buoyancy and deflated to reduce buoyancy, and/or chambers which can be filled with water to decrease buoyancy and evacuated to increase buoyancy. In this way, the float can be maintained at a desired level in the water (including submerged). Reducing buoyancy is valuable, for example, when adverse weather conditions might endanger the vehicle, particularly if the vehicle is relatively small. Such chambers can for example comprise valves, e.g., one-way valves, which are controlled by computers responding to input from sensors on the vehicle itself or from radio signals. The energy needed to inflate and/or to evacuate such chambers can be derived directly from waves striking the float, and/or from the wave power generated by the relative movement of the float and the swimmer, and/or from stored electrical power. For example, a chamber can comprise a flexible portion which will act as a pump when struck by waves, and which will either fill or empty the chamber, depending upon the position of the valves. Alternatively or addi-

tionally, the float can comprise one or more chambers with the one or more inlets through which water can enter when waves are high but not when waves are low, and one or more outlets from which the water can drain when waves are low.

(11) Equipment for collecting samples, for example samples of water, air, aquatic organisms, sea animals, vegetables or minerals.

(12) Equipment for utilizing wind energy, e.g., to recharge batteries.

(13) Auxiliary electrical equipment, for example lights, beacons, or a motor driving a propeller.

(14) Means for converting part or all of the movement of the swimmer into electrical energy.

In some embodiments, it is possible to operate simultaneously surface components, e.g., solar cells and/or radio, and a submerged component, so that data transmission can be "real time". It is also possible to plan alternating phases of data collection and transmission.

Directing the Vehicle Along a Desired Path

In some uses of the invention, the vehicle is directed along a desired geographical path with the aid of a computer attached to the float or the swimmer. The computer is used for example

(a) to process (i) input from a magnetic compass or gyroscope (preferably attached to the swimmer), (ii) input from a satellite navigation system, e.g., GPS (preferably attached to the float), and (iii) geographical coordinates preprogrammed into the computer and/or input to the computer by radio commands; and

(b) to output commands to (i) a rudder control system which controls a rudder or rudders on one or both of the float and the swimmer, preferably on the swimmer, and (ii), if the vehicle has auxiliary control or propulsion means, to those means. The input to the computer can include data available from other sources, e.g., to take account of winds and currents.

In other uses of the invention, the vehicle is directed along a path which is determined by using a computer attached to the float or the swimmer, or both, the computer being used to

(a) process input from a sensor attached to the vehicle itself, or from a network of vehicles, one or more of which are vehicles of the invention, and

(b) output commands to (i) a rudder control system which controls a rudder or rudders on one or both of the float and the swimmer, preferably on the swimmer, and (ii), if the vehicle has auxiliary control or propulsion means, to those means.

In this way, for example, a hydrophone, magnetometer or other sensor on the vehicle could identify the presence of an object in or on the water or on the seabed, e.g., a ship or other floating or submerged object, or a whale or other sea creature, and the vehicle could be directed to follow a path related to that object, e.g., to track the movement or presence of that object.

The operation of the vehicle can be controlled by signals sent to it from a remote control station and/or by signals generated by the vehicle itself, optionally in conjunction with one or more preprogrammed command structures forming part of the vehicle itself. One way of keeping the vehicle close to a fixed point ("station-keeping") is to direct the vehicle towards the fixed point at regular intervals, e.g., of 1-10 minutes. If the vehicle has overshot the fixed point, it turns at the end of the interval. Successive turns are preferably clockwise and anticlockwise, to reduce the risk of twisting the tether, and each of the turns is preferably as small as is consistent with the avoidance of twisting the tether. Another way is to direct the vehicle along a generally figure-of-eight path, with the center of the path being the fixed point, and with the vertical axis of the path aligned with any ocean current. The vehicle follows a straight line between each of the turns, and again successive turns are clockwise and anticlockwise; and, if the time spent outside a zone defined by the straight sections of the path is important, each of the turns is preferably as small as is consistent with the avoidance of twisting the tether.

In many applications, it is unnecessary to control the speed of the vehicle. However, if such control is desired, it can for example be provided by measures such as controlling the angle of attack of fins, allowing the fins to feather, and holding the fins stiff, to decrease their efficiency when less thrust is desired. If there are fins on each side of the swimmer body, these measures can also be used to steer the swimmer.

Storage and Deployment

In order to make the swimmer easier to store and transport, the attachment point between the fin and the swimmer body may include a pivot joint that allows the swimmer to be stored with the fin axis parallel to the body axis, e.g., in a canister, but allows the fin to be rotated 90° into its operating position. This joint may be sprung and equipped with a detent or the like, so that after the fin can be locked in the operating position.

THE DRAWINGS

FIG. **1** shows a float **11** is connected to a swimmer **21** by a tether **31**. The float comprises a body **111** on which are mounted solar panels **112**, GPS receiver **113**, antennae **114**, and electronics box **115**. A rudder **116** is secured to the rear of the float. Tether **31**, having an inverted Y shape with lower legs and **311** and **312**, connects the float and the swimmer. The swimmer comprises a body **211** having a nose cone **212**. Mounted on the exterior of the body **211** are fin systems **213** and **214**. Enclosed within the body **211** are electrical pass-through **215** for leg **311** of the tether, batteries **216**, control electronics **217**, rudder servo mechanism **218** and rudder rod pass-through **219**. A rudder **222** is mounted at the rear of the swimmer body and is controlled by rudder actuation rod **221**.

FIGS. **2** and **3** are cross-sections of fins which can be used in the present invention. Each comprises a rigid front spar **2131**, which may for example be composed of a sheet metal sandwich composite and/or have a steel core, a relatively inflexible central sheet section **2134**, which may for example be composed of metal and/or fiberglass, and a relatively flexible trailing sheet section **2135**. In FIG. **3**, there is in addition a relatively flexible fore sheet section **2133**, and the flexible trailing sheet is integral with a flexible outer jacket **2136**. The various sections may be bonded or held together with fasteners such as rivets **2132**

FIG. **4** is a cross-section of a tether **31** which comprises a tensile member **311**, six twisted pairs of insulated electrical conductors **314**, and a streamlined polymeric jacket **315**.

FIG. **5** is a block diagram of a control system for directing the vehicle along a desired path. Other control systems can be used.

FIG. **6** shows a generally figure-of-eight path followed repetitiously by a vehicle to keep it within a target zone around a fixed point **2** (except when it is turning outside the zone). The axis of the path is aligned with the ocean current. The vehicle follows a straight path between points **1** and **3**, passing through point **2**. At point **3**, control systems on the vehicle note that the vehicle has reached the perimeter of the target zone, and operate a rudder so that the vehicle turns anticlockwise between points **3** and **4**. The vehicle then follows a straight path between points **4** and **5**, again passing through point **2**. At point **5**, the control systems operate the rudder so that the vehicle turns clockwise between points **5** and **1**. If the vehicle is moved by wind and/or current in addition to wave power, auxiliary propulsion means may be needed to maintain the vehicle within the target zone.

FIG. **7** is a perspective view of a swimmer **21** and tether **31**. Two substantially identical fin systems, each comprising a rigid vertical post **226** and a fin **213**, are secured to swimmer body **211**. Tether legs **311** and **312** are attached to the tops of the posts **226**. Each fin comprises a relatively rigid front spar **2131** and a relatively flexible rear section **2135** shaped so that the fin can operate without striking the swimmer body; the fin optionally includes one or more intermediate sections (not shown) having relatively greater or lesser flexibility.

A hinge structure **2262** is bolted to each front spar **2131** and rotates around pivot shafts secured to the posts **226**. Each of four torsion bars **2263** is fixed at one end to one of the vertical posts and at the other end to a front spar as a location selected to provide a desired degree of control over the rotation of the front spar. Each fin can for example have a cross-section generally as shown in FIG. **2** or FIG. **3**. Rigid vertical fins **222** and **223** are secured to the trailing and leading ends respectively of the swimmer body. Fin **223** is fixed. Fin **222** can be controlled to rotate about a vertical axis.

FIG. **8** shows how the shape of the fins in FIG. **7** changes as the swimmer is pulled up and down by wave motion.

FIG. **9** is a perspective view of a swimmer **21** and tether **31**, and FIG. **10** is an enlarged perspective view of part of FIG. **9**. Two substantially identical fin systems, each comprising a rigid vertical post **226** and a fin **213**, are secured to swimmer body **211**. Each fin comprises a relatively rigid front spar **2131** and a relatively flexible rear section **2135** shaped so that the fin can operate without striking the swimmer body; the fin optionally includes one or more intermediate sections (not shown) having relatively greater or lesser flexibility.

A hinge bar **2262** is bolted to each front spar **2131**. Bars **2265** are secured to the hinge bars **2262**. One end of each bar **2265** is rotationally secured to a pivot shaft at the top of one of the posts **226**, and the other end is rotationally secured to longitudinal bar **2266** which joins the bars **2265** attached to the respective posts. Springs **2267** are secured to the swimmer body and to the bar **2266**. Tether **31** is secured to the longitudinal bar **2266**. Rigid vertical fins **222** and **223** are secured to the trailing and leading ends respectively of the swimmer body. Fin **223** is fixed. Fin **222** can be controlled to rotate about a vertical axis. In a similar embodiment (not shown), the springs are rotationally attached to the bars **2265** instead of the bar **2266**.

FIGS. **11**A to **11**D show how the shape of the fins in FIG. **9** changes as the swimmer is pulled up and down by wave motion. In FIG. **11**A, the swimmer is being pulled upwards; the tether tension increases and pulls the bar **2266** upwards, stretching the springs **2267**; the leading edges of the fins rotate downwards, and the trailing sections of the fins curl upwards, producing thrust from the bottom surfaces of the fins; and the swimmer body moves upwards. In FIG. **11**B, the tether tension remains high; after the rotation of the leading edge of the fin reaches its mechanical limit, and the trailing sections of the fins curl downwards, producing thrust from the top surface of the fin; the swimmer continues to rise.

In FIG. **11**C, the tether tension has decreased; the springs **2267** pull the bar **2266** downwards; the leading sections of the fins rotate upwards, and the trailing sections of the fins curl downwards, producing thrust from the top surfaces of the fins; and the swimmer moves downwards. In FIG. **11**D, the tether tension remains low; the leading sections of the fins remain rotated upwards, and the trailing sections of the fins curl upwards, producing thrust from the bottom surfaces of the fins; and the swimmer continues to move downwards.

FIGS. **12-21** show the swimmer of different water vehicles of the invention. In each, a swimmer **21** has a center of gravity **230** and comprises a swimmer body **211**, a nose cone **212** and a rudder **222**. Secured to the swimmer body is a fin system comprising vertical post(s) **226** and one or more fins, each fin comprising two or more of flexible inner section **2133**, rigid section **2134** and flexible outer section **2135**.

In FIGS. **12-16**, there is a single post, and a tether **31** is secured to the top of the post. In FIGS. **12-14**, the leading edge of a single fin is fixed to an intermediate position on the post. In FIGS. **15** and **16**, the leading edge of a single fin is rotatably secured about pivot point **2261** at an intermediate position on the post. In FIG. **16**, stop **2268** limits rotation of the leading edge of the fin.

In FIG. **17**, there is a single post having a bar **2265** rotatably secured to its top. The leading edge of the fin is secured to one end of the bar **2265**, and tether **31** is secured to the other end of the bar **2265**. Rotation of the bar **2265** is controlled by spring **2267** secured to the post and the bar. FIG. **18** is similar to FIG. **17**, except that there are three bars **2265** with attached fins, the tether **31** is secured to the top bar, and a line secured to the tops of all three bars and to the swimmer body includes the spring **2267**. FIG. **19** is somewhat similar to FIG. **18**, except that the three bars **2265** with attached fins are arranged horizontally and each has one end rotatably secured to a lower horizontal bar attached to two vertical posts **226** and the other end rotatably secured to an upper horizontal bar to **266**. Rotation of the bars **2265** is controlled by spring **2267** which is secured to the upper horizontal bar and the swimmer body.

In FIGS. **20** and **21**, there is a single post having a bar **2265** rotatably secured to its top. The leading edge of the fin is secured to one end of the bar **2265**. The lower legs **311** and **312** of tether **31** are secured to the ends of the bar **2265**, and leg **312** includes spring **2267**. Rotation of the bar **2265** is limited by flexible line **2268**. Fixed horizontal stabilizer fin **225** is secured to the trailing end of the swimmer body.

FIGS. **22**A-**22**C show the different configurations of a swimmer comprising a swimmer body **21** having a rigid rear section **214** having horizontal fixed stabilizer **225** secured thereto; a central section **228** which can be deformed elastically in the vertical plane but not substantially deformed in the horizontal plane; and a rigid front section **212** to which a rigid fin **213** is secured. A tether **31** is secured to front section **212**. In FIG. **22**A, the swimmer is in still water.

In FIG. **22**B, the swimmer is being pulled upwards. In FIG. **22**C, the tether tension has dropped, and the weight of the swimmer is forward of the center of lift, causing the front section to tilt downwards.

FIG. **23** shows a swimmer which operates in a way similar to the swimmer shown in FIG. **22**. The rigid fin **213** rotates relative to rigid swimmer body **211**, and the tether is attached to the top of a post **226** which rotates relative to the fin and the swimmer body, and which carries a stabilizing weight **226** at its bottom end.

FIGS. **24** and **25** show swimmers in which the fin system comprises two fins **233** which rotates about an aligned axis and are connected, at points outboard of the swimmer body, to transverse bottom legs **315** and **316** of tether **31**. The swimmer shown in FIG. **24** also comprises rigid fixed vertical fins **223** at the leading end of the swimmer body.

FIGS. **26**A, **26**B and **26**C are top, side and front views of the swimmer of a water vehicle, and FIG. **26**D is an enlarged view of the front of FIG. **26**B. The Figures show a tether **31**; a swimmer body **211** having a nose cone **212**, a rudder **222** and a COG **230**; and a fin system comprising vertical posts

226, horizontal bar **2265**, and a plurality of identical fins. Each fin is rotatably attached to the bar **2265** at a pivot point **2261** and is also secured to the bar **2265** by springs **2267** which control the rotation of the fin. Each fin comprises a substantially rigid leading edge **2131**, a relatively inflexible central section **2134**, and a relatively flexible trailing section **2135**. In similar embodiments, the number of fins could, for example, be from 3 to 8, e.g., 5, and the bar **2265** and the springs **2267** could be configured so that the movement of each fin is controlled by a single spring.

FIGS. **27**A-D show different attitudes of a swimmer as it moves through different phases of its interaction with the water. The vehicle comprises a float **11**, a tether **31**, and a swimmer **21** which comprises a body **211** and a fin which extends on both sides of the body **211**. The fin rotates about a fin axis **2137** which is at right angles to the axis of the tether and at right angles to the swimmer body axis **2117**. The fin has a chord axis **2138** which is parallel to the body axis **2117** when the vehicle is at rest (FIG. **27**A) and during the glide phase (FIG. **27**C), and is at an angle to the body axis **2117** during the kite phase (FIG. **27**D).

What is claimed is:

1. An unmanned wave-powered water vehicle which comprises:

(1) a float,
(2) a swimmer, and
(3) a tether connecting the float and the swimmer;
the float, swimmer and tether being such that, when the vehicle is in still water,
(i) the float is on or near the surface of the water,
(ii) the swimmer is submerged below the float, and
(iii) the tether is under tension;
the swimmer comprising
(2a) a swimmer body having a longitudinal axis, and
(2b) a fin system which
(a) is secured to the body,
(b) comprises a fin, and
(c) when the vehicle is in wave-bearing water,
(i) has a configuration which changes as a result of the wave motion, and
(ii) interacts with the water to generate forces which tend to move the swimmer in a horizontal direction.

2. The unmanned water vehicle of claim **1** in which the fin system has one or more of the following characteristics:

(A) it comprises a fin which rotates about an axis of rotation, the axis of rotation having a spatial relationship to the swimmer body which changes when the vehicle is in wave-bearing water;
(B) it comprises (i) a fin which rotates about an axis of rotation, and (ii) an elastic component which is not part of the fin, and which deforms elastically and thus influences changes in the configuration of the fin system when the vehicle is in wave-bearing water;
(C) it comprises a fin having a leading edge which comprises (i) a central section which has a fixed spatial relationship with the swimmer body, and (ii) outboard sections wherein the central section is more rigid than the outboard sections; and
(D) it comprises two generally laminar fins, each of which rotates about an axis of rotation generally aligned with the longitudinal axis of the swimmer body.

3. The unmanned water vehicle of claim **1** or **2** wherein the tether has one or both of the following characteristics:

(E) it comprises an elastically deformable member; and
(F) it comprises a component which transmits data and/or electrical power.

4. The unmanned water vehicle of claim **1** or **2** wherein the swimmer body has one or more of the following characteristics:

(G) it has a substantially rigid fore section, a midsection, and a substantially rigid aft section wherein the midsection is more flexible in the vertical plane than the fore and aft sections;
(H) it comprises one or more components selected from electrical equipment, communications equipment, recording equipment, control electronics, steering equipment, and sensors;
(I) it comprises a fin which influences the orientation of the swimmer body in the horizontal plane when the device is in the water-bearing water;
(J) it comprises a generally tubular housing and the fin system comprises fins which extend either side of the housing; and
(K) it comprises a generally tubular housing and vertical fin surfaces respectively adjacent to the leading end and the trailing end of the swimmer body.

5. The unmanned water vehicle of claim **1** or **2** wherein the fin system comprises:

(1) a plurality of fins,
(2) a rigid bar which is mounted on the swimmer body, and to which each of the fins is rotatably mounted, and
(3) an elastic component which is not part of a fin and which deforms elastically and thus influences changes in the configuration of the system when the device is in wave-bearing water.

6. The unmanned water vehicle of claim **1** or **2** wherein the fin system comprises:

(1) a rigid bar which is mounted on the swimmer body,
(2) a generally laminar fin which is mounted on the rigid bar, and
(3) an elastic component which is connected to the fin and to the rigid bar.

7. The unmanned water vehicle of claim **1** or **2** wherein the fin system comprises a generally laminar and elastically deformable fin having a leading edge which comprises

(i) a relatively rigid central section which rotates about an axis of rotation generally transverse to the longitudinal axis of the swimmer body, and
(ii) relatively deformable outboard sections.

8. The unmanned water vehicle of claim **1** or **2** wherein:

(1) the float comprises a satellite-based position sensor and
(2) the swimmer comprises
(a) a horizontal sensor which senses direction in a horizontal plane, and
(b) a steering actuator; and
the vehicle further comprises a computer system which
(a) is linked to the position sensor, the horizontal sensor and the rudder,
(b) contains, or is programmable to contain, instructions to control the steering actuator in response to signals received from the position sensor and the horizontal sensor, or in response to signals received from a sensor on the vehicle.

9. The unmanned water vehicle of claim **1** or **2** wherein:

the swimmer has a center of gravity, and the tether is attached to the swimmer substantially vertically above the center of gravity;
the float has a center of buoyancy, and the tether is attached to the float substantially vertically below the center of buoyancy; and
the float has a center of drag, and the tether is attached to the float in front of the center of drag.

10. A method of utilizing wave power which comprises placing the unmanned water vehicle of claim **1** or **2** in a body of water which has or which is expected to have water waves traveling across its surface.

11. A method of obtaining information which comprises analyzing information obtained from, or recorded by, the unmanned water vehicle of claim **1** or **2**.

12. A method for controlling a function of the unmanned water vehicle of claim **1** or **2** which comprises sending signals to the water vehicle.

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